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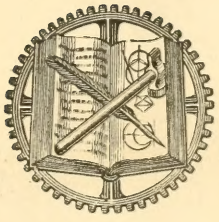
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# CONTENTS.

## VOL. XXXV.


Page

Achievements of engineering.. 148
Adieu of editor..... 524
Advances in sanitary science.. 292
Aluminium alloy, new..... 303
American academy of engineering..... 277
American watch making..... 50
Analysis of the gyroscope..... 498
Aneroids .....413, 457
Arches, logarithmic..... 17
Arches, oblique, strength of.... 193
Architectural training..... 241
Armor plate trials at Spezia... 86
Asphalt pavements of Berlin... 345
Australian railway increase ... 173
Austro-Hungarian railways.... 412
Axles, failure of..... 519

Barometric leveling..... ..413, 457
Berlin sewage irrigation works. 37
Berlin water supply..... 16
Black sea ports..... 517
Blasting agents..... 517
Blowholes in open hearth steel. 26
Book Notices.
Blas, C., Analyse Electrolytique Quantitative..... 349
Culley, J. L., C.E., Helicoidal Oblique Arches..... 349
Davies, P. J., Practical Plumbing..... 174
Cumming, Linneaus, Electricity treated Experimentally..... 523
Ditmar, W., F. R. S., Tables for Chemical Calculation. 174
Dorr, B. F., Surveyor's Guide ..... 348
Fleming, J. A., M. A., Lectures to Electrical Artisans ..... 439
Foye, J. C., A. M., Handbook of Mineralogy ..... 348
Gariel, C. M., Traite Practique d'Electricité..... 348
Gilman, Lieut. H. K., Handbook for Field Service.... 261
Gore, J. H., B. S., Elements of Geodesy. .. .. ....350, 439
Hichborn, P., European Dockyards ..... 349
Howe, M. A., C.E., Retaining Walls..... 87
Jamieson, Andrew, Steam and Steam Engines..... 522
Jennings, I. H., Photo-micography..... 261
Kapp, G., C.E., Electrical Transmission of Energy 175, 262
Randall, P., Practical Hydraulics..... 87
See, J. W., C.E., U. S. Patents on Electrical Lines.. 87

Page

Shepard, James H., Inorganic Chemistry..... 523
Staley, C. and Pierson, G. S., C.E., Separate System of Sewage.....350, 439
Wood, De Volson, C.E., Luminiferous Æther..... 175
Wormell, R., Electricity in the Service of Man ..... 523
Worthington, A. M., M. A., Laboratory Practice..... 439
Brennan torpedo..... 437
Brick masonry in design..... 435
Bridge deflection..... 447

Canadian railway progress..... 259
Cannons, Krupp..... 519
Channel-way deposit..... 394
Cholera and water supply..... 141
Columns, resistance of..... 376
Columns of steel or cast iron... 456
Combustion. ... .... ..... 451
Comparative economy..... 510
Competition by land and sea... 85
Compressed gun cotton....381, 473
Compressive foundations..... 83
Conduction, earth ... ..... 249
Conductivity of resins ..... 176
Constant cell, new..... 176
Contact, flame; water heating. 138
Cooling, rapid, of iron columns. 456
Copper mining in N. S. Wales.. 133
Cork, mechanical properties of. 307
Corrosion of boilers..... 88
Corrosion of steel..... 84
Corrosion of the copper of the Juniata ..... 207
Crane, large..... 516

Damascening by electrolysis... 88
Deep sea soundings..... 434
Defenses against torpedoes..... 521
Deflection of trusses..... 447
Deformation of the bore of a gun..... 173
Deposit from channel-way of U. S. S. Richmond..... 394
Destructive action of cement mortar ..... 344
Dissociation of steam and carbonic acid..... 87
Draining Lake Copais..... 257
Duties of the engineer..... 115
Duty on foreign coal in Russia. 328

Earth currents..... 523
Earth conduction..... 249
East Indian Railway Co. sleepers..... 173
Economy, comparative..... 510
Effect of frost on roadways.... 43
Egyptian petroleum..... 352
Elasticity of metals..... 352
Electrical motors..... 523

Page

Electrical welding..... 440
Electricity, thermo..... 192
Electric currents, self-induction of..... 62
Electric light for railways..... 516
Electric railways..... 430
Electrolysis.. ..... 523
Electromotors for railways.... 305
Electrotyping solution, new... 264
Elimination of phosphorous.... 435
Endurance of steel rails..... 76
Energy of fuel in locomotives.. 252
Engineer, duties of..... 115
Engineering academy, American..... 277
Engineering, achievements and reward..... 148
Engineering feat..... 171
Engineering Societies.
American Society of Civil Engineers ..... 433
Engineers' Club of Philadelphia.....80, 168, 516
Engines, performance of..... 183
Errors in field work, elimination of..... 108
Euphrates Valley railway..... 436
European inland navigation, 154, 222
Evaporation..... 41

Facts and science of water supply ..... 22
Fixing artesian tube wells..... 351
Flame contact, water heating.. 138
Flexure of long columns..... 376
Flooding the Sahara..... 105
Formulas for resistance of girders.....329, 353
French iron-clad as a moving target ..... 347
French railways, consumption of sleepers..... 436
Frost on roadways..... 43
Fuel in locomotives..... 252

Gas wells, measurement of..... 89
Geodesic leveling..... 466
Geodetic survey of the U. S.... 38
Girders, resistance of..... 329, 353
Girders, steel..... 297
Gun cotton for military use, 381, 473
Gun, the paradox..... 521
Gyroscope..... 498

Holland and railway enterprise. 259
Hotchkiss versus Nordenfelt guns..... 438
Hydrogen in glow lamps..... 280
Hypsometry. . .....413, 457

Ice making machinery.....122, 196
Imperial yacht..... 520
Induction of electric currents.. 62

| | Page |
|---|---|
| Inland navigation in Europe, 154, 222 | |
| Internal friction of metals | 351 |
| International Suez canal commission | 432 |
| Iron and steel, corrosion of | 350 |
| Iron, changes in due to magnetization | 84 |
| Iron-clads, Russian | 347 |
| Iron columns rapidly cooled | 456 |
| Iron enterprise in South Russia | 84 |
| Iron helmet, antique | 172 |
| Iron, protecting | 440 |
| Iron, tinned | 345 |
| Iron versus steel girders | 435 |
| Irrigation, reservoirs | 445 |
| Italian railways | 449 |
| Java volcanoes | 375 |
| Juniata, corrosion of the copper of | 207 |
| Kolomna works | 85 |
| Krupp guns | 519 |
| Kutter's formula | 256 |
| Large reservoirs | 445 |
| Leveling | 413, 457 |
| Light, standards of | 47 |
| Limit of speed in ocean travel, 71, 185 | |
| Locomotives, energy of fuel in | 252 |
| Logarithmic arches | 17 |
| Low carbon steel | 304 |
| Lunar surface and its temperature | 177 |
| Machinery for ice making | 122, 196 |
| Magnesium torch | 314 |
| Measurement of gas wells | 89 |
| Mechanical art of American watch making | 50 |
| Mechanical properties of cork | 307 |
| Metropolitan sewage | 83 |
| Modern war ships | 114 |
| Nation's great problem | 281 |
| Naval estimates, French | 520 |
| Navigation in Europe, inland, 154, 222 | |
| Navy, Spanish | 522 |
| Net defenses | 521 |
| New navy | 259 |
| New steamers for the Caspian | 86 |
| Nickel and copper | 524 |
| Nordenfelt gun | 260 |
| Norwegian industries | 524 |
| Oases of the Merv and Akhal Tekke | 82 |
| Oblique arches, strength of | 193 |
| Ocean travel, limit of speed in, 71, 185 | |
| Open hearth steel | 26 |
| Paradox gun | 521 |
| Performance of steam engines | 183 |
| Permanent way of light railways | 346 |
| Permanent way, steel sleepers for | 102 |
| Phenomenon, curious | 87 |
| Pocket heliograph | 256 |
| Polishing interior of tubes | 435 |
| Portland current, addition of substances to | 344 |
| Portland cement, magnesia in | 264 |
| Power, sources of | 487 |
| Power used in propelling street cars | 134 |
| Problem of the nation | 281 |
| Process of round forgings, new | 257 |
| Properties of cast iron | 83 |
| Properties of cork | 307 |
| Proposal for American academy | 277 |
| Pulley, new | 171 |
| Purification of water | 315, 397 |
| Rails, steel, endurance of | 76 |
| Railway accidents in 1885 | 85 |
| Railway construction in Italy | 449 |
| Railway electromotors | 305 |
| Railways, electric | 430 |
| Railways of Europe | 347 |
| Railway mileage | 519 |
| Railway of Forth bridge | 517 |
| Railway station, Frankfort | 519 |
| Railway traffic in Switzerland | 436 |
| Railway tunnels, Russian | 257 |
| Rankine's thermodynamics | 265 |
| Refrigerating machinery | 122, 196 |
| Requirements of combustion | 451 |
| Reservoirs irrigation | 445 |
| Resistance of girders | 329, 353 |
| Resistance of long columns | 376 |
| Resistance torpedo experiments | 437 |
| Reward of engineering | 148 |
| Ribbed oblique arches | 17 |
| Roadways, frost on | 43 |
| Rotary motion, analysis of | 498 |
| Rules for use of steel | 518 |
| Russian rules for use of steel | 518 |
| Sahara, flooding the | 105 |
| Sampling pig iron | 172 |
| Sanitary science, advances in | 292 |
| Science of water supply | 22 |
| Scientific experts as witnesses | 88 |
| Secondary battery, new | 176 |
| Self-induction of electric currents | 62 |
| Self-purification of rivers | 49 |
| Sewage irrigation works, Berlin | 37 |
| Sewage, treatment of | 1 |
| Sewer under Westminister palace | 82 |
| Sewer ventilation | 395 |
| Shells, gun cotton in | 381 |
| Ships of war, modern | 114 |
| Sleepers on French railways | 436 |
| Smoke nuisance | 82 |
| Solid oxygen | 87 |
| Sources of power | 487 |
| Spanish navy | 522 |
| Speed in ocean travel | 71, 185 |
| Standards of white light | 47 |
| Steam engines | 183 |
| Steel and wrought-iron girders | 297 |
| Steel in construction | 518 |
| Steel, direct production of | 257 |
| Steel, low carbon | 304 |
| Steel, open hearth | 26 |
| Steel or iron columns | 456 |
| Steel propeller shafts | 346 |
| Steel rails, endurance of | 76 |
| Steel rails for Sweden | 259 |
| Steel ships | 246 |
| Steel sleepers | 102 |
| Steel wire for bridges | 433 |
| Steel wire gun | 86 |
| Steel work for railway bridges | 182 |
| St Gothard tunnel traffic | 259 |
| Strains of ships at sea | 85 |
| Strategetical frontier railway | 173 |
| Street car propulsion, power used | 134 |
| Strength of oblique arches | 193 |
| Suez canal | 516 |
| Suez canal commission, report | 432 |
| Supply of water—relation of cholera to | 141 |
| Supply, water | 16 |
| Surface of the moon | 177 |
| Survey, geodetic of the U. S | 38 |
| Swedish navy, additions to | 348 |
| Swedish railways | 259 |
| Temperature of lunar surface | 177 |
| Testing rails and tires | |
| Test of water-tight compartments | 85 |
| Thermodynamics | 489 |
| Thermodynamics, Rankine's | 265 |
| Thermo-electricity | 192 |
| Torpedo boat | 520 |
| Torpedo defenses | 521 |
| Training, architectural | 241 |
| Tramcar, electric | 519 |
| Trans-Caspian railway | 348 |
| Treatment of sewage | 1 |
| Tyne tank steamers | 259 |
| Van Nostrand, David | 441 |
| Ventilation of sewers | 395 |
| War ships, modern | 114 |
| Water jet experiments | 524 |
| Watch-making, American | 50 |
| Water purification | 315, 397 |
| Water supply and cholera | 141 |
| Water supply of Antwerp | 344 |
| Water supply of Berlin | 16 |
| Water supply, science of | 22 |
| Wells, measurement of | 89 |
| White light, standards of | 47 |
| Wood turbine wheels | 256 |
| Wrought-iron girders | 297 |

VAN NOSTRAND'S

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## THE TREATMENT OF SEWAGE.

By Dr. C. MEYMOTT TIDY.

From the "Journal of the Society of Arts."

When, some six months ago, your Council did me the honor to ask me to read a paper before your Society on the subject of the "Treatment of Sewage," I accepted with considerable misgivings, knowing that to do the subject in any way justice would necessitate an amount of work which I was not quite sure that I had time for at my disposal. However, I accepted the duty, and I at once set to work to think out the whole matter. I had a vast amount of facts to go over, and the result has been that I have prepared a paper which it is impossible to read for two reasons—first, its length, for I think it would take almost a week to read, and, secondly, that it is not in proper form, which is a very important matter in connection with this subject. I only mention this in order to assure the Society that I have not neglected the subject which I have been asked to bring forward. Perhaps I have done a little too much, so far as that is concerned, in its preparation; and I shall have to ask you to forgive me if, instead of reading the paper, I give an outline of the conclusions at which I have arrived, and of certain facts bearing on those conclusions, and, at the same time, if I avoid, as far as possible, anything like details. These will all be printed in due course, and then the details upon which I have based my conclusions will be before the Society.

I should like to mention one or two other preliminary points. First of all, I have tried to consider this subject unfettered, as far as possible, by previous conclusions. I remember that famous saying of one we know very well, Prof. Clifford, that consistency was the bugbear of weak minds. I have not tried to be consistent. I have attempted, at any rate, to approach the subject from the position of judge, if possible, and not from the position of advocate. I come before you without any patent; I am an advocate of no system. I have been retained by a good many people on both sides in my time, and I have had an opportunity of knowing what is going on behind the scenes, and, as I say, I come here to-night without being an advocate of anybody, or anything, without any patent to support, and without, as far as I know, having written anything upon the subject which can be criticised. So that, I think I am in a perfectly independent position in this matter. Another matter which I should like to mention is my obligation to many friends in preparing the paper, and I mention that so that it may not be supposed I am taking upon myself credit for work which belongs to others. First of all, I must mention my friend, Professor Dewar, whose originality we all know. Then there are others, earnest, ardent precipitationists, like Mr. Hawksley. I

cannot mention all their names at every turn, and therefore I must, once for all, admit the obligations which I owe to them before I start.

Now, I have endeavored to come to something like a conclusion as to the proportions of solids and liquids in sewage which are contributed daily by a town population of a given number. And I have endeavored to do this as far as possible by calculations. Those calculations have been made to a great extent at the London Hospital, where we have something like 900 people, and where we have, therefore, a very good opportunity of judging. I am not going through the actual numbers to-night, but I may say that if you take a town population of 10,000 people, you will not be very far wrong in saying that the urine of that 10,000 of town population will be something like 10,300 gallons, of which from 740 to 750 lbs. is organic matter, and of that organic matter it may be taken that about 220 lbs. is nitrogen. Then, as regards the fecal matter, it may be taken that the dry fecal matter from the 10,000 town population will be about 430 lbs. There will be that quantity of dry fecal matter passed per day by that number, and of that quantity about 360 lbs. is organic matter; of that 360 lbs., something like 23½ lbs. is nitrogen. So far as I can make out, that is as nearly as possible the state of facts.

Now, then, of the constituents of this organic matter, the phosphoric acid and potash have a certain manurial value. This annual value of the excreta has been calculated by a great many different people. I do not know myself very much about the agricultural aspect of the subject, and I have therefore looked up all the estimates of agricultural writers bearing upon it. It is very difficult to make anything of them, for they vary from 6s. 6d. to £1 as the annual value of the excreta of each adult. I think you may take it that between 8s. and 9s. is more nearly the actual result than any other I can arrive at. Then we have got all sorts of calculations about the ammonia. We are told that urine, on the average, contains 10.3 per cent. My own experiments leads me to think that that is rather a low estimate of the actual quantity—decidedly low I think—when you take into consideration the fact that a large number of the population of towns are, generally, not in very good health, and that the amount of ammonia excreted during disease is not at all the same, but very often double what it is during health; however, that does not make very much difference. Then the value of the ammonia alone is something between 6s. 8d. and 7s. 6d. per year for each adult. All I want to make clear is—for this is the point I wish to arrive at in connection with this question—that the chief subject of manurial value is urine. It is very curious to see all the estimates that have been made of the relative valuations of this excreta. We have, for instance, the statement that a pound of human excrement is equal in manurial value to 13 lbs. of horse dung, or 6 lbs. of cow dung. A very famous chemist has said that the excretal value of one adult is equal in manurial value to the droppings from one sheep, and so on. I can only mention these facts to you as an introduction to my story.

Well, the first calculations with regard to the value and quantities of this excreta were made from the cesspool system and the midden system. The middens were not looked upon as sources of profit, but simply as means to prevent nuisance. Cesspools had many disadvantages; there were noxious emanations from them, polluted wells, and all sorts of things. The middens have their advantages, and they also have undoubtedly their difficulties. One of the difficulties in connection with them was that of educating the people to use them properly; a difficulty which, in my opinion, applies just as much to water-closets as to middens. Another difficulty was to get the local authorities to attend them properly, I mean with regard to the perfection of the scavenging arrangements; and I am bound to say that, in my experience, the difficulty is not one iota less in getting the local authorities to treat the sewage properly. The middens have two advantages; the first is the diversion of excremental matters from the rivers, and the second, that disinfectants can be used in middens during periods of epidemics. Those are very great advantages which we have to consider in connection with this subject.

Now, there are two matters which I have to mention with regard to a circum-

stance which was pointed out by Dr. Frankland, which is that sewage from midden towns is just as foul, just as impure, and just as polluting, as the sewage from water-closet towns. And Dr. Frankland, in one of the reports of the Rivers Pollution Commissioners (for, of course, although it was the report of the Commissioners, it was really his report), has given figures to show that the sewage from these midden towns is as bad as that from water-closet towns. I emphatically join issue with him there on the facts. My own experience is that he is absolutely wrong somewhere. I do not know exactly where, but I am perfectly clear that he is wrong, and that midden town sewage is not so bad as water-closet town sewage. And it is a very curious fact also, that it is very clear from Dr. Frankland's own results that his results show he is wrong somewhere, because he has taken this sewage of which he has given the composition from a large number of midden towns; and after giving the details showing that the sewage of midden towns is the same, or rather worse, than the sewage of water-closet towns, he says that the facts also show that an average of 25,561 tons of solid matter is annually kept out of the midden towns' sewage which has been examined. Well, I cannot make out exactly how, having come to the conclusion by elaborate calculations that out of the midden town's sewage which he has examined there is kept out 25,561 tons of solid sewage matter, he can say that the sewage is as bad in the one case as in the others. That is one of many difficulties which I have found at starting. My own calculations show that Dr. Frankland is correct in the quantity of solid matter which is kept out of the sewers, and by that quantity of course is the sewage of the midden towns improved. That is the conclusion at which I have arrived on that point; therefore, I join issue with him, and it is very important that I should join issue with him there, because it is a matter on which I shall have to speak. It is no use saying that middens, if not properly looked after, are a nuisance; of course, anything that is badly looked after is a nuisance. I only say that it is important that we should notice those facts.

It is impossible that I should go here into anything like a discussion of the merits of the dry-earth system. As regards cost, I will simply say this: that two men and one horse can, at any place where the place of collection is ordinarily near a town, collect three pails a week per head at the cost of 3s. 9d. per ton. That seems to be about the result.

And now we come to the water-carriage system. People said, "Here is this horrible stuff to be got rid of; what can there be better to get rid of it than water—wash it away as fast as possible." That was the idea—thus arose the water-carriage system.

And what is the value of the sewage thus produced? Sewage liquid, compound—very compound; complex—very complex. We may say broadly, if we want to define sewage (and I have defined it on many occasions) that it is the refuse of communities, their habitations, streets, and factories. This is not a very accurate definition, but it is somewhere about it. Now, then, as regards the quantity of sewage and the quality of sewage, I think there are two facts to be borne in mind. I have the analyses of sewage from a great many different towns which have come before me, but there are two facts which I want to bring before you, and the first is, that the quantity of sewage and the quality of sewage in one town is entirely different from the quantity and quality of the sewage in another town; it is totally different, varying with different conditions, such as the trade operations that are being carried on there. I want to show that there is a difference from that fact alone. That is a difficulty, and when we hear a man saying that this is the system of treatment or that is the system of treatment, we must remember that the sewage of different towns differ altogether. There is something else, because, secondly, I say that the sewage of some towns varies at different times of the day, and under different conditions of weather. It is no good your going down to a town at a particular time and taking a sample, and saying, "This is a sample of the sewage of the town." As a matter of fact, it is not a sample of the sewage of the town; it is only a sample of the sewage of the town which has been collected at the outfall at a particular time, and nothing else; and I think it is im-

portant, therefore, on this question of the treatment of sewage, that we should distinctly bear that fact in mind. As I say, the sewage of one town is not at all the same as the sewage of another, and the sewage of the same town even varies at different times.

Now, I am not going to discuss here any question of the advantage or otherwise of the separate system. I do not want to enter into it to-night, though I have discussed it fully in the paper I have prepared. I have no doubt of this, that for the purposes of irrigation separation is an advantage. For the purpose of precipitation, dilution, within certain limits, is not an evil, and we must remember that the question of the separate system must bring before us the question of what you are going to do with the sewage—what sort of system you are going to adopt for the purpose of getting rid of it. We must remember this, a steady uniformity of views is, no doubt, a very good thing, but a steady uniformity of views is not everything. Steady uniformity is at times a perfect nuisance; in fact, there is a great evil in having steady uniformity in everything, and especially in sewage matters. You lose the advantages in this case of a good flushing; and I do not know anything that is a greater loss than that. It is very easy to be very clever on the separate system, but I venture to say that the separate system would mean an intermittent pollution of all the watercourses of the country. There cannot be a shadow of a doubt that the foulest sewage is brought down in the first hour's rain from the washings of the streets and such like. I am afraid that, in these days, we are getting to be too much phrase worshipers. We all know the phrase about the "Rainfall to the river and the sewage to the soil." It is very pretty, but it is not correct It is all very well throwing this phrase at you, using it as an argument, but it is no argument at all.

Well, I come now to the composition of the sewage. I am sorry to say I cannot give it you exactly. You cannot tell what is the composition of sewage. It varies in a number of different ways. Suppose, for instance, I take the average of an enormous number of sewages, and say we get about 45 grains in solution and about 44 grains in suspension, I should not be very far out; but at the same time that is not a very satisfactory statement after all, because the composition of sewage differs at ever hour in the day. There are weak sewages and strong sewages, average sewages and non-average sewages. We have all sorts of sewages. The term "composition of sewage" is, therefore, simply nonsense. We cannot speak of average compositions unless you take samples of the sewage every half-hour, and then mix all the samples together, and make an analysis of the mixture of the half-hour samples during the twenty-four hours. That gives you an idea of it. But the idea of going and taking a sample merely, and saying that is a real example of the sewage of a town, is nonsense. Well, then, the great thing of course to be done was to get rid of the sewage; and the water-carriage system was introduced in order to wash it away from your houses. But, then, the next point was how to get it away from you, how to get rid of it as soon as possible; and of course the easiest way to do that was thought to be to send it into your rivers. All I can say is, that letting it go into your rivers means, for the most part, putting off the nuisance from yourselves to your neighbors. Of course it is a very easy way of doing it, but the great evil of letting your sewage go into your rivers is from the suspended matters which you have in your sewage. I do not think the other part of it makes much difference. The matters in solution do not make much difference if they are well mixed, because they soon got oxydised. Everyone believes that, I think, except one or two individuals, nowadays, and I will say no more upon it. Then with regard to the solid matters, we generally find that the solid matter flows about the outfall; but some of the matters in solution combine with the aluminous constituents from alluvial soil, and so forth, and become insoluble, and then we get a curious sort of suspended matter. We find, for instance, the manurial matters going down first, and then, as the mixture of sewage and water flows on all the organic matters, of varying density, go down. Of course those that are lightest or most flocculent of all go down last, and very often that is the most offensive

of all kinds of organic matter; so that when you let your sewage matter go into your rivers, you do not, perhaps, get much nuisance near you, because, of course, the organic matter has gone down lower. The organic matter sinks to the bottom of the water, and there undergoes putrefactive decomposition, until after a short time the gases developed are sufficient to render this material specifically lighter than the water; then it comes up, gives off its gases, becomes heavier, goes down again to putrefy once more, with other matters added to it, then comes up again, and gives off other gases. That is the history of suspended matter introduced into the river in that way.

Well, it was quite clear that would not do. People could not stand that sort of thing, and so they set to work to see what they could do with their sewage in some other way. Two things could be done with it; but let me put one first. It was absolutely necessary that one thing should be done with it; that is to say, that it should be purified, that was certain. And the second thing was that, inasmuch as the sewage had a certain manurial value, it was desirable to utilise whatever valuable constituents were present in it. Those were the two conditions required. First, to get what you could out of it, and next, to make it as pure as possible. But there was something else. Of course you must purify it, or else there would be litigation, and therefore you must do that, and you ought also to do your best to get all you could out of it; but whatever you did with it, you must do it without causing a nuisance. Those were the conditions, that you must purify it, and that you must get what you could out of it; but you must do both without committing a nuisance.

Now comes the question of the value of sewage. It is wonderful how people talk, or rather how they used to talk—they do not talk quite so much about the value of sewage now. The basis of the calculation is simplicity itself. There can be no doubt we can easily calculate the value of sewage. Dr. Corfield does it in his book with the greatest ease in the world; you get your population, you find the quantity of the excreta, you find out the constituents and the relation of one to the other, and there is your calculation. Well, it was very curious that a calculation so simple as that should have brought forward a heap of authorities who differed very widely as to what the value of the sewage was. I have just been looking through the evidence which was given before the Select Committee of the House of Commons in 1862, and there the authorities differed between a halfpenny and 9d. a ton. It was very curious, seeing the simplicity of this little calculation, that they should differ so much as that. They said there was nothing easier than to calculate the value of your sewage, and yet they differed so widly as that—between a halfpenny and 9d. The interest, of course, of this whole matter is centered in the value of the sewage of London; and I have been trying to get together the views of all the people who have views on the subject, for the purpose of seeing what I can make of it. There is a class, which I will call the cautious people, who, taking the population as 3,000,000, estimated the value at 6s. 8d. per head, and they calculated the value of the sewage of London as £1,000,000 a year. Then there was another class of less cautious people, Mr. Brady and Lord Robert Montagu I will put amongst them, who thought that to take 6s. 8d. was nonsense, and they made out the value of the sewage of London as £2,890,000. Then there was a class of very heroic people, as I will call them, numbering amongst them eminent chemists, and they calculated the value of the sewage of London as £4,081,430. Those are the different opinions which have been given about the value of the sewage of London. When you asked them about it, they said, "Our calculations are based on the teaching of science." I am carefully using their own words, that they were "based on the teaching of science." Well, of course, if this sewage is of this extraordinary value, we must try and get something out of it to help to pay the rates, and people said—let us apply it to London. That naturally resulted. Enthusiasts fully believed in its value, and arithmeticians and scientific men were found to start sewage farms. I see before me a very distinguished man, who, I think, was one of the earliest of those who tried the plan, but a certain unpleasant awakening occurred with regard

to all this. Science told its story, and through the mouths of its authorities, some of whom I see before me, told that story well. They told us how the land acted,—how it was a mechanical filter, and a chemical laboratory at the same moment; how as a mechanical filter it took out the solid matter; how as a chemical laboratory it effected the oxidation of the nitrogen which the plants took up and utilised, and brought back again for our use as food. They told us how the churchyard feeds the village sheep; how the sheep feed the villagers, and how the villagers feed the churchyard herbage. They were always telling stories of this kind. Science talked in this way, but then the farmers had something to say about it. They said, "All that is true, no doubt; your learned societies say so, and, therefore, it must be true."

Still the farmers had their own views on the subject, and their views led to this conclusion, that they would only take the sewage at such times as they liked, and in such quantities as they required. What is the result? Some great and learned people thought the farmer very foolish, very ignorant, and very obstinate. I do not think I am putting that too high. They traced the obstinacy of the farmer to his conservatism—I mean his blind attachment to old-fashioned ways, good and bad. The facts did not support this view, still they stuck to the fact that the folly of the farmer was his conservatism. Well, the farmer does not quite follow this conservatism in everything; he shows his appreciation of newly invented manures; he thoroughly understands the value of superphosphate. He is not conservative in that. He is not conservative in adopting new agricultural implements; he does not show any blind attachment to old fashioned ways there, but he did in this matter of sewage. Mr. Chadwick preached with the authority of a Board of Health at his back. I will quote his own words, so that there shall be no mistake about it:—"That liquid manure was at all times preferable to solid manure, and suitable for all crops, and all soils;" but Mr. Chadwick's sermon fell upon bad ground. Mr. Chadwick piped, and the farmers refused to dance. Seeing that this part of the subject was a failure, gentlemen farmers set to work. They set to work for the purpose of teaching the farmers, but after a while even the gentlemen farmers gave it up. They learnt a lesson at some cost, and left off their work, sadder, wiser, and poorer men. Mr. Chadwick still preached, but the people began to suspect one or two things, either that there was some obstacle to the agricultural use of sewage, or that its theoretical was not its practical value. Local authorities too found this, that if they had to apply sewage to land in order to purify their sewage they must secure the land, they could not trust to the farmers taking it. Why? Now comes the part of my story that is important. Why did they require land? First, that the sewage might be taken at all times, day and night, Sundays and weekdays, all the year round, summer and winter, whether the soil wants it or not, or there are any crops or not, and at all stages of their growth, seed time and harvest. The farmers did not see the force of that. Secondly, they found out that it was necessary so to purify the sewage as to produce an effluent which, under every consideration, should not produce a nuisance, nor pollute a watercourse. The farmer looked after his crops; the local authorities looked after their effluent, and the two things did not agree. The farmer said, "I admit a certain manurial value; I am not going to dispute that science teaches it; I should not care to discuss the question with science; but on the whole, having given the subject my consideration, I prefer to sacrifice the manurial value rather than be compelled always to have the water." That was the conclusion of the farmer.

Besides, he says, "it is no use your pointing to other countries, and telling me what a wonderful thing irrigation is in India, and in Continental places, and so on, that will not do; temperature is against us here; wet weather is against us; look at frost" (and I shall say something about that before long); "allow your ground to remain quiet and aerate it, which was necessary, and the ground freezes; neglect to aerate it, and it is no good." That is the first great difficulty. It is no good telling me about the increased temperature of sewage, and I

shall have something to say about that before long. Frost, rain, and storm, water-logged land—the very time when you have the most sewage to deal with, the ground is in the worst condition to take it. Hot weather cracks your clay, if you have clay, and down goes the sewage without being purified at all.

Dr. Carpenter, who is an ardent irrigationist, has pointed out the difficulty of management, and there are some remarkable passages in Dr. Carpenter's paper, when he was, perhaps, forgetting himself a little on that point. Increased cost — the Local Government Board know something about that in their report. Then we come to this curious fact, that you cannot get one single point upon which these ardent authorities are agreed. I have been trying to see if we can get a starting point on which they are agreed. They do not agree upon the method of application—whether it shall be by hose and jet or not. "The soil best suited is very porous soil," said Professor Way—and he knows a good deal about it; "a heavy soil," says Liebig—and he knows a good deal about it; and then others go between the two. Then some say that the crop most suited is rye-grass, and I think they are right. Others hold different opinions.

Now comes a crucial question—How much sewage *qua* agricultural success, can properly and, *qua* sanitary success, safely, be applied to a given area of land? Now I will ask you for a few minutes to regard this question of area before 1870 and after 1870, and, I was almost going to add, after April 14th, 1886; but I will take it, if you please, before 1870. The agricultural and the sanitary aspects of the subjects were not in accord. To realize your agricultural success you must apply a large quantity of sewage to your land, and that you know they did. Realize your sanitary success, and then the rule is, apply a smaller quantity, the smaller the better. So you have for agricultural success to get as much as possible out of sewage; and for sanitary success, in order to purify it to have as little as possible. Can you split the difference? The authorities differ between 2 and 800 as to percentage. Mr. Mechi said 2, but he altered his views afterwards; Mr. Hope said 20 or 30; Mr. Way and Sir Robert Rawlinson 100 consistently; and I think I shall not be unfair if I state it thus, that the authorities on the subject all say (and recollect I am speaking of before 1870) that 100 is the minimum to pay, and then a great many other persons said that 30 was the maximum to escape prosecution.

Our Friend Dr. Frankland saw that difficulty. He saw what I will call the land difficulty; he saw this, that the greater the quantity of sewage that you have the more land you required, and the less land there was to have. For a very large town there was very little land in its neighborhood. A small town had plenty of land, but there was very little sewage. Not only did you require more land where you had more sewage, but the higher was its price. Dr. Frankland grasped that difficulty, and he said to himself, I have no doubt irrigation is doomed, unless I can find out some method of concentrating a large volume of sewage on a small area of land. Well, Dr. Frankland in this, as he has done in a good many other difficulties, saw a way of escape. In the year 1870, Dr. Frankland set to work to make a series of laboratory experiments. He took a cube foot of earth, and calculated the amount of sewage that that cube foot of earth in his laboratory would purify. I am very particular about this, because a certain letter in the *Times* of to-day, about which I shall have something to say hereafter, necessitates my drawing attention to this. I am sorry Dr. Frankland is not present to hear the criticism which I have to offer; but I know he is some distance off, and therefore cannot get here. A cube foot he makes the experiments upon—and wonderful experiments they were. These laboratory experiments gave birth to a system called intermittent downward filtration. Just let us see the conditions, and I will represent things as fairly as I possibly can. First, he says, you must have "suitably constituted soil." I am using his own words. It is difficult exactly to say what he means by "a suitably constituted soil," but I suppose I shall not be far wrong in saying that he means a soil not too open, so that anything may pass, and not too close, so that nothing will pass. Then he says (and let us be clear about this) as the essen-

tial part of intermittent downward filtration you must have deep draining, and that is fixed at 6 feet. I am using his own words, because his calculations are made upon 6 cubic feet, so as to allow a considerable distance for percolation. So that, if one foot will do so much work, six times that number will do so much more. This is Dr. Frankland's principle of filtration as opposed to irrigation, but it is intermittent. Dr. Frankland says there is something like a lung action—a constant taking in and giving out; he says he copies Nature. Dr. Frankland makes his experiment on this cube foot of earth, and inasmuch as this cube foot would do so much work, he calculates what six cubic feet would do, one on the top of the other, and he calculates 3,300 persons to the acre. He says I have got a new intermittent downward filtration, and I can put a large bulk of sewage on a small plot of land. Now, let me illustrate this with a case. I am going to try to give you an account of what, I suppose, is the intermittent downward filtration. Suppose I had a population of 9,900 on three acres; subdivide each acre, as he says, into four parts; put on each of those four parts your sewage of 3,300 for six hours; take it off, put it on another part, that gives 18 hours' rest to each part of your acre. That is the intermittent system. Of course there were people who went far beyond Dr. Frankland. We had a further development suggested. I fancy it was suggested that of those three acres the one should be used one year, and that the sewage of the 9,900 people should go upon that for that time, while the others rested. That might very fairly and properly be called intensified intermittent irrigation. I do not think I am using a wrong phrase. Let us not in any way misunderstand Dr. Frankland. I am not saying a word against him, because as a matter of fact no one knows the subject better than Dr. Frankland. But of this intermittent downward filtration, Dr. Frankland said that it involved the sacrifice of agricultural property. It is fair that we should be distinct about that; he always said it involved that sacrifice. I refer to that because some of his followers take a different view; my friend, Mr. Bailey Denton does; I know he thinks otherwise. He thinks that intermittent downward filtration is the best way of getting a good crop.

Now, I want to consider a new aspect of this case; the sewage without the removal of the sludge (because this is the principle of Dr. Frankland) is put upon the ground. But two insuperable difficulties occur, and I am now speaking of the results of my own experience on this subject. The first is that, as the result of this application of sewage to land, you destroy your land as a filtering agent; that it is not, at the end of a year or two, what it was when you commenced; and, secondly, that it is almost certain that you have a nuisance. I am going to take these two points, and enlarge upon them. First of all, then, I would note that Mr. Bailey Denton (and he knows this subject exceedingly well) contends that when you put that sewage with the organic matter in it upon the land, and dig it in, as he says you ought to do—it undergoes decomposition—renders the ground lighter and better by increasing its filtering capacity. That is Mr. Bailey Denton's contention. From that statement I absolutely and entirely differ. Now, just let us consider it. The sewage is applied, with the matters in suspension, to the ground. For 18 hours you apply none. The fact is that you get over a certain surface of your ground a covering which is practically impermeable, and which is not removed at once when the sewage is again applied to the land. It is curious what it is. There is first of all a considerable quantity of albuminous matter, but it is something else. We know the immense quantity of paper that goes into the sewage; now all this disappears. That is a remarkable fact; but what becomes of it—it gets beaten up into a kind of *papier maché* in the sewage; and it is that *papier maché* I think which clogs the ground; you dig it in; it simply fills up the pores with a glutinous and *papier maché* cement, and you may put any amount of sewage on you like, but it will not go through. I know that to be true, for I have tested the subject with every possible care as to the relative power of earth for allowing sewage to go through after its application. It clogs the land; your land deteriorates. Now comes the 3,300 per acre. I suppose there was no greater authority than Mr. Bailey Den-

ton on intermittent downward filtration. When he had to treat the sewage of a population of 13,500 at Kendal, he suggested 16 acres of land for the process; but the authorities did not see this, they had the report of the committee before them, and they said 3,300 to the acre. They were very liberal to him, and suggested $5\frac{1}{2}$ acres, but it did not answer. I must say, I do not like to enter upon this now, but the letter of Dr. Frankland in to-day's *Times* has rather astonished me; he has come down, at any rate, to 2,000 to the acre; but I want to show what an extraordinary result we have got. Dr. Frankland's results were based on this—a cube foot of earth would purify a certain quantity of sewage, and, therefore, six cubic feet, one under the other, should purify six times the quantity. He tells us here that this conclusion is drawn from the Warrington experiment, and that, inasmuch as it proved that the purifying action only takes place near the surface of the land, it is only necessary to drain the soil something like 2 ft. deep instead of 6 ft.; but where have his own experiments gone? His own experiments were based upon the cube foot of earth; the power it possessed to purify a certain quantity of water multiplied by a certain number, but now he has abandoned it. Dr. Frankland's letter has rather put me out. I do not know where we are.

I cannot help coming to the hygienic aspect of the subject, because it has a medical aspect too. First of all, we cannot hide from ourselves the nuisance from offensive emanations on the ground; we have seen it over and over again. The evidence is abundant. Can it be otherwise? Injurious matter on to the ground, the water allowed to drain, and its material kept upon the surface; evaporation occurring; evaporation means the carrying, not simply of water in the air, but a considerable quantity of solid matter, that is carried off during the time of evaporation. For instance, you go into a room newly painted, and you get lead poisoning. How? It is not due to the volatilization of the lead, but the turpentine, in the act of evaporating, carries solid lead into the air. That is the explanation of the lead poisoning; when the smell has gone the danger has passed. What do you do here? You have a thing which of all others you want to keep out of the air, and you spread it over a large surface of ground. I will not enter into another aspect of the question, which, from a medical point of view is immensely important—I mean the saturation of a district with moisture. This would not be the place to enter upon it, but I may say the masterly research of Dr. Buchanan has clearly shown the danger of that.

Then we have pollution of subsoil water; we have the distribution of undefecated sewage, containing the ova of entozoa and other things which I might mention. That is irrigation. I want to be very careful about what I am saying. I do not for one single moment mean to say that there are not cases where irrigation should not be properly used. When I come to discuss, as I hope I shall before I have done, the question of how you are to treat your sewage, I shall emphatically say you cannot treat it this way or that, but you can treat it in various ways at different places, and irrigation may be one of them; I am only saying that irrigation is not the way to meet it universally—it cannot be.

Now let us review our facts. We have dilute sewage to deal with; we desire to be sanitarians, to purify our sewage, so that it shall not pollute our watercourses, and in purifying it not to cause a nuisance. We desire to be economists, viz., to get from the sewage all that is valuable in it—in a word, to achieve by one and the same operation a sanitary success and a commercial profit. In sewage, as in other things, you cannot combine the incompatible. To achieve your commercial success, you must abandon sanitary considerations, and you must, as at Edinburgh, flood your land with 10,000 tons per acre per annum, until your farm is a stinking morass and your effluent water so impure that you must take it directly into the sea lest it foul your watercourse. Achieve your sanitary success, sprinkle your 300 tons on your acre with hose and jet, and away goes agricultural profit.

Try a compromise between the extremes of 300 and 10,000, and the chances are you get the difficulties of both and the advantages of neither. I admit possible exceptions. Do not misunderstand me. I say again I admit

possible exceptions. A small population, cheap land removed from human habitations, a porous soil admitting free percolation, good gradient not requiring steam power, proximity to the sea, so that extreme purity of effluent is not demanded, and proximity to a town, so that a ready sale for the rank sewage grass for dairy purposes could be secured. But the difficulties are enormous. I must have enough land, and the greater the population the greater the quantity of land required, and the larger its price. I must have proper land, sufficiently porous, but not too porous. I must have land properly levelled and properly drained. If the level of my drain be above the sewer outfall, I require costly motive power. The larger the quantity of sewage, as in wet weather, the less able is the already overcrowded land to deal with it. Frost or snow, the work has still to be done. At all times the effluent must be sufficiently pure, lest litigants be aroused. At all times the operation must be conducted without offensive effluvia from an over-sodden state of soil, and without polluting the air by rendering it abnormally damp or affected by sewage effluvia. Without polluting the air, I say, for that means typhoid. The subsoil water must be so diverted that neighboring wells shall not be polluted. Grant all these difficulties overcome, and there remains in the produce of my farm a grass unfit for dairy purposes, and likely to be a source of entozoic infection to men.

Now I come to precipitation. Let us understand what precipitation is:—The addition of certain chemicals whereby the deposit of the solids in suspension, and some of the dissolved matters is effected, together with the deodorization of the offensive constituents. I have taken the trouble to go through, so far as I can make out, nearly all the patents which have been suggested for the purpose of precipitation, and dry work it has been. I have endeavored to find out where they have been used; and I have got information from the different places as to the results. I think you may say this, that those agents principally employed are practically lime, salts of magnesium, salts of alumina, salts of iron, alone, or mixed up one with the other, in all sorts of proportions; whilst in addition some people put a certain amount of weighting matter to carry the precipitate down, and others an absorbent matter to absorb the gases. I want to put it that there are, to my mind, five conditions as to a proper precipitant; first, that consistent with purity, the chemicals used should be cheap. Secondly, that the precipitants should act as deodorisers and disinfectants. Thirdly, that the maximum purity should be obtained with the minimum of deposit, that is in the smallest possible quantity of chemicals. Fourthly, that the precipitated matters should subside rapidly. Fifthly, that the sludge should part with its water rapidly. I think these are the five conditions of success so far as precipitants are concerned. I have here some tanks which have been kindly sent to me by the A B C Company. In one we have the crude sewage and in the other the effluent, and I will ask Mr. Page to add some of the A B C material to the sewage in one of these tanks, in order that we may see how the precipitating action goes on; but I wish it to be understood that I am not here to advocate this or any system. The A B C system, I will say at once, produces in my own experience, and in that of Professor Dewar, who was conjoined with me in a research on the subject, a very good effluent. I am not going to say any more than that. Those who have had an opportunity of investigating the subject will admit that it does produce a very good effluent; that is all I say.

Now, I come to the practical question, the question asked, I would say, all over the country, and the question asked of those who have to advise on these matters, in tones almost of painful despair. How shall we deal with our sewage? I want to say this, there is no one single answer to be given to that question. The adviser must, if he wishes to do justice, sink his hobby. I do not care whether it is the hobby of precipitation or the hobby of irrigation—he must sink his hobby. He must be prepared to find conditions under which he would advise irrigation, and conditions under which he would advise precipitation. And let me say he is certain to find (in my own experience they are to be found) conditions that are favorable to one hobby at one place, but are absolutely inconsistent to that hobby at another. I want to

say this, too, that it is no good people holding up success at one place as an argument that that process will be successful everywhere. It is no good to have sewage works at A, and to take people from B, C and D down to those works at A to see how successful they are. That will not do. We have to consider the place, and we must be prepared to adopt any process that is the best fitted for that place.

Let us consider one or two general points. I am going to quote the words of my friend Sir Robert Rawlinson, "towns must be prepared to pay to be clean." That is what he said once in this place. You must purify your sewage at the expense of the rates.

[Sir Robert Rawlinson took exception to the expression "purify." "Clarify" was the proper word.]

I do not argue about the word; towns at any, must pay to be clean. Secondly, and I think Sir Robert Rawlinson will agree with me in this—I know I am on tender ground with him—the sewage must be got rid of—I am sure he will let me use my word, purified—at any cost. Minimise the cost, he would say, but you must do it at a cost. and there must be an annual expenditure. Thirdly, and I think we shall agree here, that the sewage requires constant attention; you cannot be attending to it one month and leaving it the next—you must be always at it.

I would say this, it is not simply applying to the Local Government Board, and having an inspector to go down and see whether he will grant borrowing powers for certain works. That is all right enough, Local Boards do not mind doing these things sometimes; but Sir Robert Rawlinson will tell you, I am sure, that there is something else wanted. It is not the borrowing of ten, twenty or forty thousand pounds, but it is the yearly expenditure to keep up those works that is necessary. Fourthly, to allow your sewage to go into a river means passing your filth on to your neighbor. The sewage ought to be treated, in my opinion, where it is produced. Litigation is, in my experience —although I may have derived advantages from it—a more expensive luxury than sewage treatment, and on the whole I think it breeds far more ill-will. Fifthly, I think Sir Robert Rawlinson will go with me here—that in treating our sewage we do not want a drinking water, and we do not want a Peruvian guano. Now, we go to a town, and the sewage has to be treated. We ask how much there is to treat, and what sort of stuff is it?—that is to say, what are the manufactures, and so forth. Our very first thought necessarily is, and it would be my thought first—irrigation. The local authorities must get land. It is no use talking about farmers; you must get land. To get land is a very difficult thing; and when you get land, you have to pay a fancy price for it generally, especially if it is for sewage. And there is something else about it; that all the people who have land in the neighborhood of your proposed sewage farm suddenly discover that all their land is building land. Now come certain questions. Is it practicable? And I think I may put it thus. There are three questions we ask ourselves, supposing we think about irrigation. Is it practicable to obtain sufficient and properly situated land for the purpose; sufficient—I am not going to define that now; properly situated as regards general character, level and so forth. Secondly, is this properly situated land reasonably near to the town, so that the cost of conducting the sewage shall not be excessive; reasonably distant, so that the town may not derive injury from a nuisance likely to cause disorders. And then, thirdly, is the land of such level that the sewage can readily reach it? There is a fourth question, Where is the effluent to be discharged?—and I beg to submit that this is a very important question in any irrigation scheme. You are dependent for effective purification on effective land in effective order. But land becomes ineffective from circumstances over which you have no control. First, for instance, frost; second, in times of heavy rain, land is water-logged, and when there is most sewage to be treated, your land is least able to treat it. If, then, the outfall be into a river where considerable purity is required, and not only purity, but unfailing continuity of purity, then it appears to me that an irrigation scheme must be regarded as an unsafe scheme. But where there is a discharge of an effluent, or the discharge of a little

doubtful water at times, or a little doubtful sewage, that is a matter of secondary importance, and it appears to me your irrigation scheme may pass.

My own experience of all kinds of schemes (and I think I have seen most) has led me to prefer by a very long way indeed a combination of a precipitation and an irrigation scheme; and I see for it two great advantages. First, its efficient working is independent of weather; second, if you have sufficiently large works, any emergency of quantity can be met. I am bound to say this, looking over the papers of people who have written on this subject of precipitation—and precipitation has its greatest and heaviest enemies in its advocates—one is perfectly astounded at the extravagant advantages which have been claimed for precipitation. The sludge has been advertised, and is advertised, as of enormous manurial value. Patents by the hundred have been taken out. Precipitation advocates have invariably been the advocates of a system, and no doubt the public began to doubt everybody and everything. They have taken the claims advanced by the precipitationists, and they have weighed them in the balance of facts, and they have found them wanting. I think you will believe, after that statement, that I am not here as the advocate of a system. I said the A B C turned out a good effluent, and so it does. My own experience leads me to speak very highly indeed of the use of lime, and sulphate of alumina. Put in your lime first. Your lime does three things—it produces carbonate of lime, acts as a weighty material; some of the lime is combined with some of the organic matter in solution, something like a quarter or a fifth of it, into an indescribable chemical compound. The rest goes to make the water alkaline. Then add the sulphate of alumina; the alumina sets free the ammonia, which combines with the sulphur; it acts as a mordant, and down it goes. That is not a patent. Now, I am bound to say this—I have never yet seen an effluent from a precipitation process that has not a slight smell about it; but it is not the smell of sewage, it is the smell of effluent, *sui generis*. Now, let that effluent, after precipitation, flow over a small area of land, and you give your effluent the final finishing touches towards purification. Just think of it from three points of view. You cannot cause a nuisance in that act because you get no suspended matter, and you get nothing on the surface that will decompose and give off offensive matters. You cannot clog your ground, because the materials that were in solution are precipitated. Thirdly—I attach no importance to this, because I do not think anything of it; there is a certain manurial value. The quantity that it takes varies with the land—about 5,000 to 10,000 per acre will do. Such sewage works are no nuisance. Your process is carried out in wells, your tanks are little more than ordinary pure water tanks, with no more smell; and your sewage, when it gets on the land, has no smell either.

This subject of precipitation has occupied me a very great deal, and I venture to put forward five points to which I wish to draw your attention. First, if you want to treat sewage properly by a precipitation process, you must treat it fresh. I am not going to define what "fresh" means, but I mean before active putrefaction sets in; it may be twenty-four hours or it may be forty-eight hours; it varies with the time of year, or with the chemicals that are allowed to go in from various manufactories. Of course one change has probably occurred, and that is the breaking up of the urea. I do not know anything more wonderful than the absolute disappearance of urea; by the time the sewage reaches the works an enormous quantity must be broken up. Then there are all these different decompositions, and you must deal with it before the first active change occurs. As a matter of fact, fresh sewage has very little smell at all. Then, secondly, I think it advisable, as a rule, before you mix your chemicals with it, in order to minimise your chemicals, that you should strain your sewage in some way or other. You cannot strain it entirely, but Mr. Baldwin Latham's apparatus seems to work exceedingly well. I have seen it working, and some method of that kind should be adopted. Then, thirdly, you should add sufficient chemicals to effectually complete purification. It is a great mistake to starve your chemicals. I know as a fact that local authorities will spend money on work s

but when it comes to actual working year by year, and day by day, then it is they fall through. My friend, Sir Robert Rawlinson, knows that is the test; it is not the borrowing of £40,000, it is spending £800 or £900 a year in doing the work after they have got the works.

I do not like to enter on this subject of sufficient chemicals, especially in view of a report I have here. I have very strong views about it; but will not enter upon them now. I will only say this, that I am astonished that, when I proposed in a certain scheme five grains of lime and five grains of aluminum, one of the gentlemen who signed this report showed to a certain inspector how absolutely useless it was to add that quantity of chemicals to sewage, and said it would lead to no result at all. I say nothing about that for the present, though I may have something to say on another occasion and in another place. I want simply to say, with respect to these chemicals, that my strong conviction is that the quantity ought to be calculated on the population and not on the sewage. I have always felt that most strongly. Then fourthly, it is very important that there should be efficient stirring after the addition of the chemicals. You may add your chemicals, and it will produce no effect; give it a good stirring up; we chemists know the value of a stirring rod. Then, fifth, it is essential that you should have sufficient tank accommodation. I have worked that out as far as I possibly can—sufficient tank accommodation—for two reasons: 1st, that the precipitate should subside perfectly, that is important for the flocculent matter to go down; and secondly, that the sludge may be frequently removed. It is important that the sludge should be frequently removed from the tanks for two reasons. First, if you allow the old sludge to remain in the tanks, it is perfectly certain that it will contaminate your fresh sewage after it is treated, when it comes in; and you must have it sufficiently large, or the sludge at the bottom will undergo decomposition, and render the sewage impure after you have treated it; and, secondly, that when removed you may not get any smell—that is to say, that it may be done sufficiently frequently. Another thing which is very important is this, that when the sludge is taken out of the tank, the tank itself must be washed. It is those bits that get left in which cause so much nuisance. There is nothing like cleanliness in the treatment of sewage.

In these circumstances, the question arises, Have you produced such an effluent as will not pollute your watercourses or prove dangerous if discharged into a river used for drinking. I say that by combining precipitation, which will produce a good effluent with land treatment, or prepared filters, or something of that kind, you may produce the best effluent that is known. The late Royal Commission — Lord Bramwell's Commission—in a very able report, dealt with that, and stated that as their conclusion. I am not saying whether I agree with the report so far as London sewage is concerned, but as to that being the best method of dealing with sewage as an abstract question, I do agree with it.

Then, secondly, comes the question, is not the sludge an inevitable cause of nuisance? It was formerly. I am not certain that the materials in suspension were not a greater nuisance when taken out of the sewage than when left in it, I sometimes used to think they were. I will not discuss now the quantity of sludge, but I would say as a general principle, consistently with efficiency, produce as little sludge as possible; first, because if it has any value, you secure its maximum value, and, secondly, if it has no value you have the less to get rid of.

Now, I will say a few words on the disposal of sludge; and it is almost my last point. A great change has been wrought lately by the introduction of Mr. Johnson's press. It has almost revolutionized the question of precipitation; to my mind it has quite done so. This sludge was always our bugbear—we never knew what to do with it. The principle of Mr. Johnson's press is this: You have a series of compartments in which there are canvas bags; the sewage is compressed into these compartments by means of air pressure, about 120 lbs. to the square inch, and then the material is thoroughly pressed in these presses, the liquid is pressed out, and the solid part remains in the compartments as a solid cake, of which I have a large speci-

men here. It is perfectly compact, very easy to handle, and has not very much smell. I do not say it has none, but not very much. The water is reduced from 90 per cent. to about 50 per cent., and I should like to draw attention to the fact that the liquid which is expressed from this sludge—and they generally put in a certain amount of lime, which renders it more easy of pressure—is of a very foul nature. This was a matter investigated by Professor Dewar; we worked at it some time in common, and we found it was very unadvisable ever to return the liquid from the sludge press into the ordinary sewer, which was formerly the plan. It cannot be re-treated in the ordinary way; it requires a different kind of treatment, by chloride of lime, and some other things which I will not refer to now. It must not go back into the sewer, but must be treated by itself. I am quite clear on that point, and it can easily be done. It renders the sewage into which it is returned somewhat difficult to treat, besides being itself not treated. I have considered in some detail the value of this sludge, and the cost of dressing it, and I may say the dressing costs from 2s. to 2s. 6d. per ton. That, I believe, is a wonderfully practical method of doing it. I have walked about in the middle of thousands of tons of this stuff, and really smelt it very little. My own opinion is that Johnson has done a very great deal to change the precipitation works from being a great nuisance into being comparatively no nuisance at all.

It would not be fair in this room to pass over General Scott's process, which was very ingenious. His process was to take the sludge, which was precipitated with lime in this case, drain it, and then dry it by heat, and burn it in kilns, grind the clinkers, and use it as a hydraulic cement. And I believe General Scott said that the cement thus prepared was worth something like 35s. a ton. I cannot help thinking that may be all very true up to a certain point, but at the same time it is very evident that the sewage varies in different towns enormously, and that it would be difficult to get a cement of a constant character; and it is a very important thing, so far as I understand engineering work, that cement should be of a very constant character.

Then, thirdly, there is the destructor, and, to my mind, the destructor has reached its highest state of perfection at Ealing, from the great thought that Mr. Jones, the surveyor of Ealing, has given to it. His sludge there is mixed with house refuse and burnt. Mr. Jones's view is that every town produces sufficient house refuse to burn the sludge. One has to notice the differences of destructors. I have seen a good many myself, and I should say the differences are mainly two; first, a certain escape of offensive vapors from the shaft, and I think those offensive vapors are mainly due to partial burning—the destructive distillation, as a matter of fact, of the materials, instead of their complete destruction; secondly, the escape of fine sand and such like from the shaft at certain stages of the operation. I have seen those two nuisances very well marked, and I had occasion to advise on them on more than one occasion. I cannot help thinking myself that in Jones's destructor, where he places a muffle furnace or "fume destroyer," as he calls it, between the furnace and the main shaft, he has, in a great measure, met those two difficulties. I think, myself, that Jones's destructor is a very creditable thing.

I feel rather a difficulty in saying a word on the subject of standards, and yet I do not know that one can altogether omit it. I can only say that Professor Dewar and myself found out the absurdity of comparing a sample of raw sewage with a sample of effluent. People go to a sewage works, and take a sample of sewage and a sample of effluent and compare them, which is of course manifestly nonsense. You can only compare them by taking, say, half-hourly samples of effluent and half-hourly samples of sewage, mixing them all together and comparing the average. You cannot compare a sample of sewage with a sample of effluent, for this reason. Say they are both taken at twelve o'clook. The twelve o'clock sewage, say, is strong sewage, but the twelve o'clock effluent probably is the effluent of the six o'clock sewage, when it is at the weakest; so that you are comparing the effluent of a very weak sewage with very strong sewage,

or it may be the opposite. You cannot compare one sample with one sample taken at the same time, or compare them in any way except by taking averages. Of course, it is very important in taking samples by which you are to come to any conclusion that you should know the weather, the average flow, and so forth. Now one word on what may be called a practical standard. We always hear about standards, and they are not very satisfactory. We had the Rivers Purification Bill, which I am very glad to say the House of Commons in its wisdom turned out. That was a very great point, because it was a very bad bill, altogether bad both in principle and in theory. We want a bill, however, to keep sewage out of rivers, and we ought to have it. We must leave the manufacturers alone for the present. It is quite hard enough in our days for people to get a living, and we must not be interfering too much with trade. I do not mean to say that will not come, I think it will; but we cannot do everything at once. But I will tell you what we can do. We know sufficient about sewage now; the Local Government Board has taught us a good deal, doubtless. At any rate, we do know enough about it to know that we can purify it, or clarify it, up to a certain point. And I think we ought to keep our sewage out of our rivers, and it is the duty of the local authority to do it. But we cannot be having elaborate chemical tests. Let us have some common sense standard. Something of this sort I may throw out as a suggestion. First, that your effluent shall be clear and colorless when seen in a white pint cylindrical bottle. Secondly, that it should not be alkaline to test paper—you can get that, and an alkaline effluent is not a good effluent. Thirdly, that on the addition of a grain of sulphate of alumina, or say, one grain of alum, dissolved in 100 grains of water, added to the pint bottle, it shall not produce appreciable turbidity after standing thirty minutes—you can get that. Fourthly, that if you take that white cylindrical bottle half filled with sewage, and shake it up, it shall not leave foam or much froth after standing ten minutes. These are practical tests.

I do hope the day is not so far off when we shall have some means by which we can persuade local authorities to purify and deal with their sewage. But I say again that if we are to do it, we must not act as the creators of a hobby, we must be prepared to sink the hobby; we must not go as violent irrigationists, because it is clear that that will not do; we must not go as violent precipitationists, it is clear that will not do. We must be prepared to consider what is the best method to treat the sewage of the place for which we are called upon to advise.

I cannot help feeling strongly on one other subject. I know we cannot alter it; we have this water-carried sewage to deal with; but one cannot help asking the question, if one were called upon to advise for another London, or in another planet, should we advise the water-carriage system? I have thought this subject over very earnestly lately. The advocates of the water-closet system urge that water, as a vehicle to carry the refuse, commends itself to us on the ground of cleanliness and cheapness. They would compare, and do compare, the natural power of gravitation, such as is made use of by the water-closets, with an organization of men and carts such as is required, for instance, by the midden system. I confess the advantages at first sight are all on one side, but I must say there are some facts which point in the opposite direction. Diluting with water is the very best known method of rendering whatever is valuable in sewage practically worthless, and sometimes an ungovernable nuisance. The excreta of animals are no doubt intended for the food of plants, and, again, for us through their intervention. Of course, do what we like, do what we please, nature will assert herself and assert her plans, although it is certain we do our very best to embarass nature by meddlesomeness, but the nutritive food of the plant we drown with water, and then our ingenuity fails to deal with the filthy mixture. We cannot utilise it unless we abandon all sanitary precautions. It pollutes our air; it may render our ground a simple stinking morass, and defile our watercourses. Let me put it to you; here in London 30 gallons of water per head is brought from pure sources, let me say, at great cost, with vast engineering skill, filtered, and per-

haps refiltered with extraordinary care, stored with scrupulous anxiety, analysed by one chemist after another, and what for? About one-ninetieth part of the water is used for drinking purposes, and a large quantity is destined to be the mere diluent of our sewage, to perplex us by its uselessness, and to steal our health with the perpetual nuisance it creates.

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## EXAMINATION AND TESTING OF BERLIN WATER SUPPLY.

From Abstracts of the Institution of Civil Engineers.

The testings of the Berlin water during the period from July 1, 1884, to April 1, 1885, have been regularly carried out, in accordance with the plan agreed upon between the Director of the Municipal Waterworks, Mr. Gill, M. Inst. C. E., and the civic authorities. The chemical analysis was arranged as follows:

1. Estimation of the residue from the evaporation of 200 cubic centimetres of water, dried for five hours at 110° Centigrade.

2. Estimation of the volatile portion of the residue by calcination, moistening the ash with carbonate of ammonia and again calcining it at a low temperature.

3. Estimation of the chlorides by titration of 200 cubic centimetres with $\frac{1}{10}$ normal silver solution, according to Mohr's system.

4. Estimation of the ammonia (after separation of the lime, magnesia, iron, &c., by means of soda-lye and carbonate of soda) by calorimetric tests of the liquid decanted from the residue, with Nessler's solution.

5. Estimation of the lime by titration of the amount of oxalic acid necessary for the precipitation of the lime, by means of chameleon solution, on Mohr's system.

6. Estimation of the oxidizability in a solution of sulphuric acid, on boiling for ten minutes, on Kubel's system.

The investigations for nitro-organisms were both microscopical, and by means of pure cultivation on a solid medium (10 per cent. meat juice-pepton-gelatine).

Few variations in the chemical composition of the water of the Spree and that of Lake Tegel were observed, but the contents in micro-organisims fluctuated considerably. The Spree water is richer in chlorides and in substances capable of being reduced in an acid solution by the chameleon tests, also in fertile germs of micro-organisms. An appreciable amount of ammonia could only be found in the Spree water, and this reached on one occasion 0.23 milligram per litre. The water of Lake Tegel only showed on one day a measurable quantity of ammonia, viz.: 0.04 milligram per litre. The efficacy of the sand filters is next examined. On all occasions the contents in organic matter, chlorides, the oxidisability and micro-organisms were reduced by filtration, but the dissolved lime was slightly increased. The tests on March 2d showed that the filtration had only reduced the fertile germs in each cubic centimetre from 963 to 468, whereas in the previous week the reduction had been from 210 to 68, and in the previous fortnight from 250 to 28. This led to an exchange of correspondence with the Engineer, and to the discovery that, owing to the formation of a thick sheet of ice over the uncovered filter-basin, it had been impossible to cleanse it.

Daily examinations were made of the water from each of the filter-beds, to test their action with respect to yield, endurance, rapidity of yield under pressure, and influence of temperature, and these tests were made in comparison with the unfiltered water. Comparative investigations were also made respecting the efficacy of open and covered filter-beds, and the fact was established that the open filter-bed removes considerably more fertile germs than the covered one. Precautions were taken to test most carefully for the *crenothrix polyspora*, both in the freshly-collected samples and in those which had stood for twenty-four hours, but on no occasion was the presence of this conferva detected by microscopic examination of the water from the

Spree. It was, however, often present in the water of Lake Tegel. The investigations generally prove that the water-supply is rendered more or less impure after leaving the source, either by the distribution through the pipes or by storage in the high-pressure reservoir at Charlottenberg. Nothing, has, however, transpired to indicate, either chemically or microscopically, the presence of injurious agents of any description in the water of Berlin.

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# LOGARITHMIC AND RIBBED OBLIQUE ARCHES.*

By JOHN L. CULLEY.

Written for Van Nostrand's Engineering Magazine.

## Chapter VII.

### LOGARITHMIC METHOD.

69. This method of constructing oblique arches is so-called because naperian logarithms are used in their calculations.

The soffit coursing joints by this method are always normal to the plane of the arch face, wherever they come in contact with it, and hence it is these coursing joints are normal to any plane parallel with the arch faces at their points of contact in the parallel plane. The soffit heading joints are elliptical curves in planes parallel with the arch faces, and are, therefore, normal to the coursing joints of the soffit at their intersections. The heading and coursing joints of the soffit being thus normal to one another, they will also be normal to one another in the developed soffit.

70. Fig. 36 shows the plan and development of the soffit of a semi-circular oblique arch, whose elevation and right section is shown at A B C and H I J. The curve N X′K normal to the curve S X′G at its middle joint X′ is the developed soffit coursing joint through that point. Through the middle point R of the spring line S O, draw the dotted line R P parallel to the curved ends of the soffit S G and O Q. Divide R P thus drawn in to any convenient number of parts of equal length (Fig. 37) and through the point of division, draw their coursing joints parallel to the curve N X′R. The widths of the courses are thus determined on the middle curve R P, in order to show the same order of arrangement and of size of the several courses in the arch faces, but their dimensions may be fixed on any other parallel curve to R P. It will, however, be found most convenient to take the middle curve R P, and also to make the courses of one width on this curve.

71. Having thus determined the position of the coursing joints in development, the heading joints are drawn in the several courses at desired or convenient points, and their elliptical

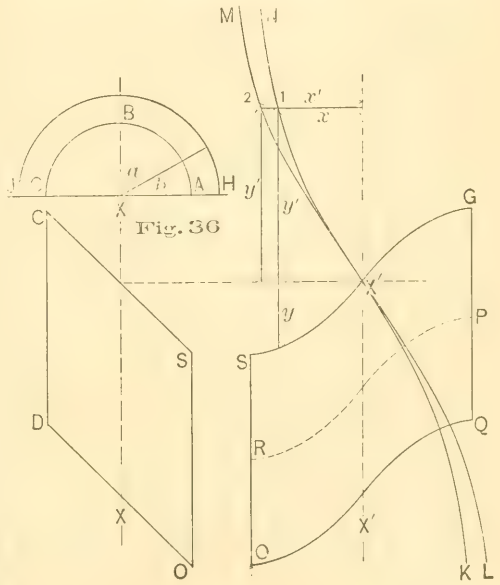



Fig. 36

curves are drawn parallel to R P, or to the curves of the developed arch ends. It should be borne in mind that the heading and coursing joints in the development are drawn parallel with R P and with N X′R on lines parallel to the spring lines S O and G Q. Thus, if we cut out a cardboard templet, one of whose edges

* Copyright, 1886, by John L. Culley.

will correspond with the curve N X′K and its left-hand edge is straight and parallel to S O, and through the points of division in R P we draw the several coursing joints shown in Fig. 37, this templet should be moved so that its left hand straight edge shall always be parallel to the spring line S O. In like manner the heading joints may be drawn with

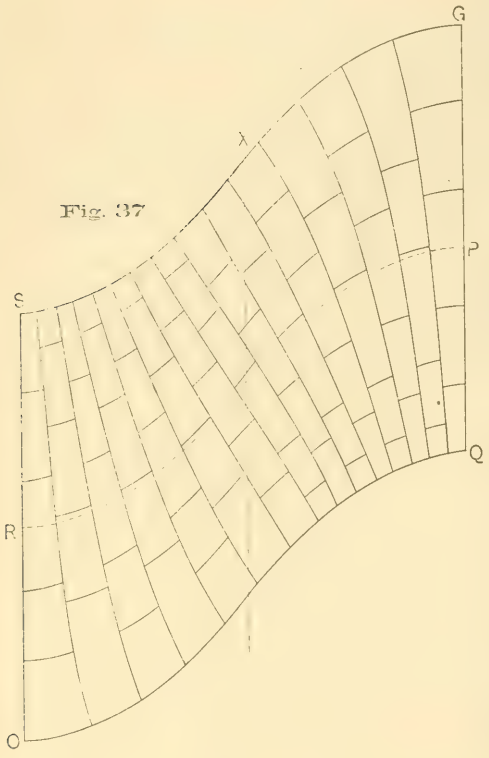



Fig. 37

a templet of curvature S X′G, but in moving it over the development S O Q G, its extremities S and G should always move on the spring lines S O and G Q, whilst the curved face of the templet moves parallel to the end curves S G and O Q. These precautions should always be observed, otherwise the curved lines drawn would not be correct or in accordance with the requirement of article 69.

72 The equation of the normal curve N X′K to S X′G at its middle point X′ will now be determined.

In article 41 will be found the expression

$$y = r \sin.\ a \text{ tang. } \theta \qquad (32)$$

Now since $x$ is dependent upon $a$ for its value this equation contains a ratio of $x$ to $y$, and is therefore an equation of the end curve S X′G, and might be used for it in place of equation (17). Let $b$ be the complement of $a$, and we have

$$y = r \cos.\ b \text{ tang. } \theta \qquad (33)$$

Again $a$ is usually expressed as so many degrees, or as W. 180°. It is in fact the length of an arc of $n$ 180° to radius unity. Thus, the expression tang. 36° means the tangent to an arc of 36° to radius unity, but not the tangent of 36°. $a$ therefore equals $n\,\pi$,

$$\text{but } x = n\,\pi\,r, \qquad \therefore\ x = r\,a \qquad (34)$$

$$\text{but } a = \frac{\pi}{2} - b, \qquad \therefore\ x = \frac{r\pi}{2} - rb \qquad (35)$$

Differentiating equations (33) and (35) and dividing we have:

$$\frac{dy}{dx} = -\frac{r \text{ tan. } \theta \text{ sin. } b\, d\,b}{r\, d\, b} = -\text{tan. } \theta \text{ sin. } b \qquad (36)$$

Now, let $y'$ (Fig. 36) be the ordinate to any point in N X′K that $y$ is for the corresponding point in S X′G for the ordinate $x$. At an infinitesimal distance from the point of contact X′ the curves N X′ K and S X′G are straight lines. Thus, in Fig. 38, let X′ be the origin of co-ordinates X′Y the axis of $y$, and X′X that of $x$. Now, if on X X′ we lay off an infinitesimal distance X′B, and through B draw A C parallel to X′Y, the curves A X′ and C X′ are exactly at right angles to one another within these limits, and the ordinates to A will be:

$-dx$ and $dy'$ and the ordinates to C will be

$-dy$ and $-dx$. The triangles AX′B and BX′C are similar, whence

$$-dy : -dx :: -dx : dy',$$

or

$$\frac{dy}{dx} = -\frac{dx}{dy'} \qquad (37)$$

but $\frac{dy}{dx} = -$tang. $\theta$ sin. $b$ (see eq. 36)

$\therefore \frac{dx}{dy'} =$ tan. $\theta$ sin. $b$ (38). But $dx = -rdb$

or $dy' = -\frac{rdb}{\text{tan. } \theta \text{ sin. } b} = -\frac{r}{\text{tan. } \theta} \cdot \frac{d\,b}{\text{sin. } b}$

$$= -\frac{r}{\text{tan. } \theta}\,\frac{db}{2 \text{ sin. } \frac{1}{2}\,b \text{ cos. } \frac{1}{2}\,b}$$

$$= -\frac{r}{\text{tan. } \theta} \cdot \frac{db \cos.^2 \frac{1}{2} b}{\text{cot. } \frac{1}{2} b}$$

$$= \frac{r}{\text{tan. } \theta} d \text{ log. cot. } \frac{1}{2} b \qquad (39)$$

$$\therefore y' = r \text{ cot. } \theta \text{ log. cot. } \frac{1}{2} b + C \qquad (40)$$

or, substituting $(90° - a)$ for $b$ we have:

$$y' = r \text{ cot. } \theta \text{ log. cot. } \frac{1}{2} (90° - a) + C \qquad (41)$$

as the equation of the curve N X′K in which if

$a = 0$, $x = 0$, and log. cot. $\frac{1}{2} (90° - a) = 0$

or $C = 0$,

whence the equation of NX′K becomes

$$y' = r \text{ cot. } \theta \text{ log. cot. } \frac{1}{2} (90 - a) \qquad (42)$$

wherein, if $a$ and $x = 0$, $y = 0$

if $a = 90°$, $x = \frac{\pi r}{2}$ and $y = -\infty$

if $a = -90°$, $x = -\frac{\pi r}{2}$ and $y = \infty$

By the aid of Eqs. (42) and (32) the soffit coursing and heading joints in the development may be determined with great precision.

73. *The coursing beds of oblique arches by the logarithmic method are generated by a radial line normal to, and moving along the axis of the arch as one directrix, and on a cylindrical curve as the other directrix, which at all points is normal to planes parallel to the arch faces.*

This second directrix is usually taken in the soffit, and we will so treat it here, but should be in cylindrical surface, midway between the intrados and the extrados.

74. The great similarity in the generation of the coursing bed surfaces by the helicoidal and by the logarithmic methods. It should be noted both are generated by a radial line normal to, and moving along the axis of the arch. Their difference is in the fact that, in one case the second directrix is a helix, and in the other, a normal curve to the arch faces. It matters little what this second directrix is so long as its curvature is known. But it is of the greatest importance that we keep in mind that the first directrix is radial in the logarithmic just the same as it is in the helicoidal method; nor should this idea, in the treatment of oblique arches by either of these methods, be ever lost sight of. It is the fundamental principle and renders these two methods quite similar in construction, and for this reason the treatment of logarithmic arches is readily understood when the problems connected with helicoidal arches have been once mastered.

75. Again, it should be noted the only straight line elements in the coursing beds by either methods are radial; that is, they are in lines normal to the axis of the arch, and consequently, are always normal to the coursing joints, both intradosal and extradosal. The only straight lines in the soffit, by either methods, are lines parallel with either the axis or the spring lines of the arch, nor should this fact be lost sight of.

76. Now, if NX′K (Fig. 36) is the intradosal joint and MX′L the extradosal joint of a coursing bed passing through X′ in the development, and if through any point 1 in NX′K we draw 1 2 in direction perpendicular to $s_1 o$ continued, the point 2 in MX′L is the intersection of the radial element through 1 in NX′K. We have already determined the ordinate of 1 to be

$$y' - r \text{ cot. } \theta \text{ log. cot. } \frac{1}{2} (90 - a) \qquad (42)$$

but $y'$ is also ordinate of the point 2, and Eq. (42) is therefore the equation of MX′L when

$$x' = r'a \qquad (43)$$

## Chapter VIII.

### METHOD OF WORKING THE VOUSSOIR.

77. Reduce the face of the stone to be worked to a true cylindrical surface by aid of the soffit templet, Fig. 25, in the manner as described in article 57. This reduction may be accomplished in a variety of ways, but the method there described is believed to be the simplest and best.

Let A B C D, Fig. 39, be the soffit thus reduced, and let A′B′C′D′ be the developed soffit of the voussoir to be worked. Through B with the straight blade of the soffit templet draw the element B E, and through B′ in the development draw corresponding line B′E′ parallel to the spring lines, or to the axis of the arch, and through D′ draw D′F′ parallel to B′E′, and through A′ and C′ draw A′G′ and C′F′ perpendicular to B′E′ and to D′F′, respectively. Lay off on B E, B G and G E equal to B′G′ and to G′E′.

Then with the curved blade of the soffit templet through G and E draw the circular arcs G A and E C, whose respective lengths shall be equal to A′G′ and E′C′ in the development.

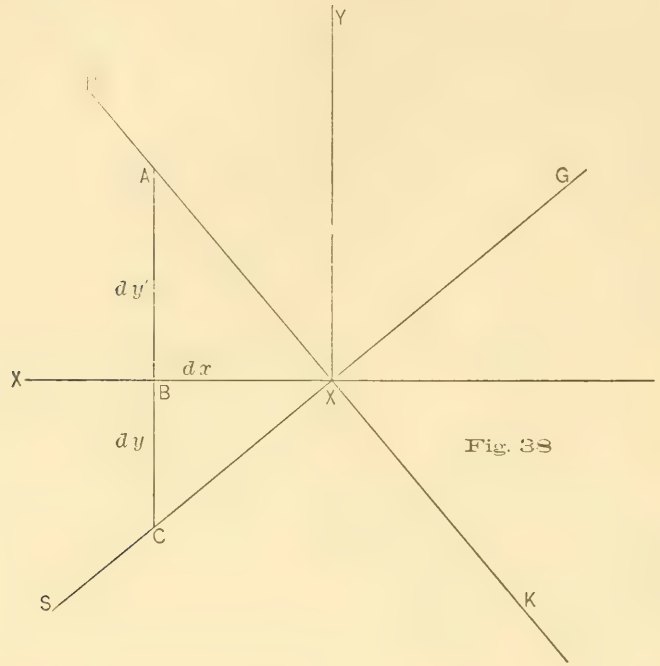



Fig. 38

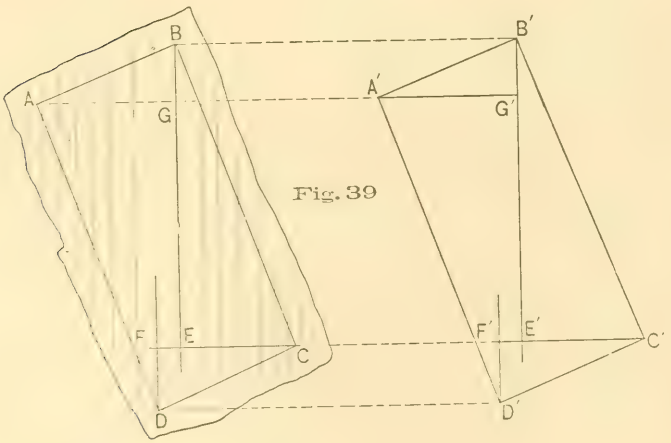



Fig. 39

Produce the arc E C to F and make E F equal to E′F′ in the development, and with the straight blade of the soffit templet draw the element F D parallel to B E, and make F D equal to F′D′ in the development. The four corners A, B, C and D of the voussoir soffit are now determined.

78. The heading and coursing joints of this soffit are reduced in a simple manner. Thus let a flexible rule of cardboard, thin hard wood, or other suitable material, be cut, with one edge of the exact length and curvature of the developed joint A′B′, and apply its extreme points A′ and B′ at A and B, press the rule against the cylindrical soffit, and

cause it to thoroughly conform to this surface, and whilst so applied, work on the soffit between A and B the line of the curved edge of the rule, and the joint A B will be determined. The joints B C, C D and D A may be thus determined by rules cut to their developed curves, and then applied to the worked soffit of the voussoir in like manner as A B was determined.

79. Another way of determining the voussoir corners and joints in the worked cylindrical soffit is: Let any corner B, Fig. 39, be selected as before, and through it draw the element B E. Then cut a templet of cardboard, or of other flexible material, to the exact size of the developed soffit A′B′C′D′, and draw across it the line B′E′ parallel to the spring lines of the arch, and apply this templet with its corner B′ at B and its line B′E′ on B E, and cause the templet to conform throughout to the worked cylindrical soffit surfaces, and when so applied, work all the edges of the templet on the stone, and thus determine all the joints of the soffit at one operation.

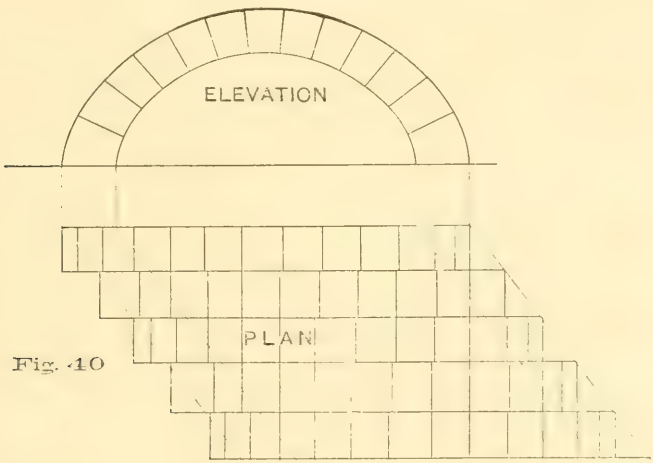


Fig. 40

REDUCTION OF THE COURSING BEDS.

80. When it is remembered that the coursing beds by this method (logarithmic) are generated by a radial line, it will at once appear that the coursing bed templet, Fig. 28, is as applicable to logarithmic arches as to helicoidal arches for the reduction of the coursing beds, when the coursing joints have been located upon the worked soffit of a voussoir.

81. The surfaces below the joints A D and B C, Fig. 39, are therefore worked to the radial edge of this templet. When so worked, radial lines are drawn with this radial edge on the coursing beds through the corners A, B, C and D, thus determining the lines of intersections of the heading and of the coursing beds of the voussoir. The heading surfaces are then worked to these radial lines so drawn, causing the surfaces to be normal to the soffit, and therefore normal to the coursing beds.

82. Much has been said as to what should be the character of the heading coursing surfaces, both by the helicoidal and by this method. It has been maintained that these surfaces, by the logarithmic method, should be planes parallel to the arch faces; that the strength and stability of the arch demanded it, &c. It in fact matters little, whether these surfaces are parallel to the arch faces or are warped surfaces, normal to the coursing beds. It is, however, the author's opinion that the latter construction is the more stable. It has the advantage, also, of simpler construction.

83. The arch face stones are to be worked precisely in the same manner as described in Articles 63 and 64 for helicoidal arches. In the one the coursing joints are helicoidal, whilst in the other these joints are curves, normal to the arch faces. The same principles are in-

volved here as there, and therefore do not require a second demonstration.

84. The logarithmic method of oblique arch construction is one that requires great care and constant supervision to successfully execute. It should be done in the most systematic manner. Thus it will be noticed that the courses increase one side of the arch while they decrease in thickness on the other side of the arch from one end of the arch to the other. Yet, two courses beginning at opposite ends of the arch at the same height above the spring line are exactly alike in all their dimensions. Their voussoirs may therefore be worked in duplicate, which, in fact, is the proper way to treat this class of construction. These two courses may be laid out at once, and all their voussoirs worked. There is no reason why all the voussoirs of the entire arch may not be worked out before any of them are set in position in the arch. All the voussoirs of a course should be kept separate and distinct by themselves. Every voussoir should be marked in plain figures or characteristics, indicating at once its course and position in it.

85. The coursing joints of every course should be marked permanently on the centering, as a guide for the voussoirs as they are set in position. This is best done by transferring to the centering ordinates taken from the development plan of the arch soffit.

RIBBED OBLIQUE ARCHES.

86. Oblique arches are sometimes constructed by placing several narrow elliptical arches or ribs, as they are called, together, as shown in Fig. 40. This method is very faulty, and cannot be too severely condemned. There is no bond between the several ribs, as each rib is separate and distinct in its construction and its position; the load above the arch is never uniform throughout the whole length of the arch, and on account of this lack of bond in the arch, it will be distorted by its unequal settlement. Again, the outer ribs are constantly being forced outwards by the action of frost upon the material that finds lodgement between their heading surfaces. So serious becomes this weakness that the ribs have to be reconstructed to restore the stability of the arch. True, these ribs are sometimes bonded one to another with iron straps, yet this bungling device is devoid of transverse strength and is susceptible of taking up the longitudinal stress only. Such an arch is not to be compared to an arch of bonded courses. Again, if it is properly bonded with iron straps, a ribbed elliptical arch costs more than an oblique arch constructed in accordance with the rules of any one of the recognized methods of proper construction.

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## THE FACTS AND SCIENCE OF WATER SUPPLY.

From "The Engineer."

A MASS of interesting particulars with respect to the water supply has been presented by Colonel Sir Francis Bolton and Dr. Percy Frankland, in the form of two lectures recently given before the School of Military Engineering, at the Royal Engineers' Institute, Chatham. These lectures refer to the collection, storage, purification, and examination of water. In dwelling on the various sources from which a supply of water may be obtained, it is mentioned that in England the three principal water-bearing strata are the Chalk, the Lower Greensand and the New Red Sandstone. Of these three the chalk has the largest outcrop, but its geographical position is such that it receives a much smaller rainfall than the new red sandstone, so that the actual quantity of water absorbed by the latter stratum is probably the greater. The quality of the supply also has the merit of not being so hard. Still, we are told the chalk will always be the best source of supply, as the stratum is easy to work, and should a well fall on a hard spot the difficulty can be overcome by driving galleries from the bottom, and thus increasing the volume collected in proportion to the ramification of the

workings. The extent to which water can thus be obtained is said to be "almost unlimited." We must observe, however, that there is considerable significance in the "almost:" There are ancient reservoirs in the chalk, which may yield liberally for a time, but which may ultimately become exhausted. The regular annual yield will then have to be relied upon, and this is limited, though large. Allusion is made to the intention of the East London Waterworks Company to seek for an extensive supply on the burrowing principle. This company has applied to Parliament for power to raise new capital, in order to drive several miles of tunnels underneath its own property in the Lea Valley, by which means it is hoped to be able to dispense altogether with the intake from the river Lea as a source of supply. Unfortunately there appears some risk that the company will withdraw its present bill, owing to a dispute with the Select Committee as to the appropriation of the dividends in connection with the new capital. It is to be hoped that this difficulty may be bridged over, so as to permit of so desirable an experiment in water supply as that which the company contemplates. Next week will most likely see the question settled one way or the other, so far as this session is concerned. South of the Thames we find one of the companies sinking a deep well at Streatham, hoping possibly to reach the lower greensand, failing which, the supply will be taken from the intervening chalk. The sands above the chalk also yield largely, giving up two million gallons per day at Streatham, with the probability that more may be obtained by employing pumps of greater power. The Streatham well, as many of our readers probably know, has been credited with a disastrous effect on the lesser wells in the vicinity, and, indeed, at some distance. The intercommunication between wells in the chalk is notorious, and gives rise occasionally to rather awkward consequences. Happily the law is now interpreted as protecting underground waters from pollution, otherwise deep wells in the chalk might be looked upon as fraught with more danger than open rivers. With regard to a river supply, the Thames affords a striking example of the extent to which springs in the chalk supplement the volume obtained from surface drainage. It is calculated that one-third the total rainfall of the Thames basin flows down the river, though the surface drainage of such a level district cannot amount to more than one-fifth.

The effect of filtration on the quality of water is discussed in these lectures with some minuteness. It is evident that on this point we are gaining fresh light, and fortunately our increased knowledge is directly calculated to augment our confidence in the filtering process, where that remedial method is intelligently employed. It is generally supposed that two actions take place during the passage of water through a filter—the first a mechanical one, whereby the solid particles are arrested; and the second a chemical one, consisting in the oxidation of those bodies contained in the water which are capable of oxidation, and caused by the layer of air or condensed oxygen which surrounds each particle of sand composing the filter. The lectures tell us—and most likely the utterance is that of Dr. P. Frankland—that it is impossible to say how far the action of a filter is dependent on each of these two properties. "But," says the speaker, "we rather incline to the belief that the first is the principal one, and that the chemical action, if it exists at all, is very slight." There is said to be very little evidence in favor of the chemical action of a filter, while some things point directly to its absence. On one point there is no uncertainty, and that is the necessity of cleaning filters from time to time. The only rule in this particular where the London Water Companies are concerned, is that a filter should be cleaned as soon as it requires more than a given head of water to get the proper quantity through. There is hope that a more satisfactory rule will shortly be available, and the lecturers are making investigations for this purpose. But besides the artificial process of filtration, two of the Thames companies are now using an auxiliary process of filtration through the natural gravel beds which form the banks of the Thames at Hampton. These gravel beds are at all times full of water, forming a species of underground river. Perforated pipes were laid in the gravel and connected with a pumping well in order to utilize

this water, which is always clear and bright on account of the natural filtration which it has undergone. But the supply from this source was found to be small, and in order to effect an increase it was determined to flood the bed with water direct from the Thames. For this purpose a second series of perforated pipes was laid parallel, to act entirely independent from the first, and at about thirty yards distant. This second series of pipes was placed in direct communication with the Thames, but provided with a small vertical sand filter to arrest the coarser impurities. The result of this arrangement is so far important. The yield of the pumping well has been considerably increased; 3,000,000 gallons per day of perfectly filtered water are obtained from forty acres of ground, and the appearance of the water is not affected by the turbidity of the river. A suggestion almost inevitably arises, that if artificial filters require frequent cleansing, it may happen that a natural filter, treated thus artificially, may in time become foul. But the assurance is given that "this will certainly not take place for many years." The softening process effected by the use of lime is spoken of in these lectures as being excellently adapted to well water, but as being less easily applied to Thames water, as the suspended clayey matters prevent the carbonate of lime from settling completely, and a filtration is therefore rendered necessary, which offers more difficulties than the ordinary filtration, as the particles of carbonate of lime penetrate far into the sand and soon choke the filter. The Royal Commission on Water Supply in 1868 came to the conclusion that softening by the use of lime was not applicable to the Thames water.

We may add that the Chemical Commission of 1851, while recommending that Clark's process should be applied to chalk waters, went on to say: "But it seems that it is not to river waters that this elegant and useful purifying process is most advantageously applicable." The proposal of the commission was that chalk waters, softened by this process, should be resorted to for the supply of the metropolis. The Royal Commission of 1868 did not take up this recommendation, but relied on proper filtration and due care in excluding polluting matters from the river.

The examination of water, with a view to detecting its impurities, affords a peculiarly interesting subject at the present time. While exaggerated fears are being dispelled, more effective precautions are likely to be taken against the inroads of disease. Already we are provided with the means of testing the efficiency of filtration, so as to be aware when a filter has lost its purifying power. A welcome discovery is furnished by the fact that micro-organisms are largely eliminated by the action of such filter-beds as appertain to the works of the London Water Companies. In testing the results of this filtering process, the impossibility of obtaining water absolutely free from the presence of microphytes has to be recognized. It was stated at Chatham that "all natural waters contain micro-organisms." There is no reason to be alarmed at the fact, for it is added—"by far the greater number of these are of a perfectly harmless character." This circumstance complicates the question, but at the same time it lessens the apprehension that would otherwise arise. The biological examination of water which is now coming into vogue, consists in discovering the relative abundance of these micro-organisms, and in ascertaining, if possible, whether any of them are dangerous to health. Tested by modern processes, even the morning due is not pure, nor the hoar frost that sparkles on the leafless bough. The rain is somewhat better, but all are touched by impurity of some kind or other, gaseous if not animal. A table given in one of the Chatham lectures shows that the average of dew and hoar frost contains more than twice as much organic carbon as the West Middlesex supply, and three times as much organic nitrogen. The total combined nitrogen is less than in the average of London water, and rain is purer than dew, but with more organic carbon and nitrogen than occurs in the New River supply. Rain serves to wash the atmosphere, but due and hoar frost are formed in the lowest stratum, where the impurity is greatest. Even if we resort to distilled water, we there encounter gaseous pollution. By "pure water," therefore, for all practical purposes we

should understand not that which the chemist calls pure, but that which contains nothing prejudicial to health in the case of a drinking supply, or nothing calculated to destroy the success of a technical operation when the water is intended for industrial purposes. If all the microphytes are to be looked upon with suspicion, we must even view the supply furnished by the Kent Waterworks as of dubious quality. Not only are micro-organisms discovered in the Kent supply as it reaches the consumer, but they exist in the water as it is pumped up from the deep wells in the chalk. Strange to say, the well often contains more of these organisms than the supply. The Kent water is not filtered, and hence there is no straining out of the microphytes, which probably multiply after a brief stimulus from the light received on their way from the well to the mains. Filtration has an immense effect on the river waters, taking out from 94 to 99 per cent. of the organisms. Last month a sample of water taken from the Thames at Hampton, and treated by the Koch process, yielded 11,415 "colonies," indicating so many original organisms, per cubic centimetre. A sample of West Middlesex water taken one day later, and treated in a similar manner, yielded only 175 "colonies" per cubic centimetre. In January the supply from the Lea exhibited a yet more striking reduction.

The extent to which the water supply may become the vehicle of zymotic disease is a doctrine now brought into much narrower limits than were formerly understood. It is found that most of the substances ordinarily present in water, and which, chemically speaking, are impurities, have little or no influence upon health. Danger has to be sought in matter of an organic nature. But it is not all organic matter in water that is to be considered dangerous. The evil has to be sought in organic matter arising from animal excreta. The circle has to be drawn yet narrower, for sewage-contaminated water is daily consumed by multitudes of people without any prejudicial effect. The peril presents itself when the sewage is derived from persons who are suffering from disease. The argument put forth at Chatham on this point is that sewage may at any time become infected, and consequently all water which "has been" contaminated with sewage should be condemned for drinking purposes. In its logical severity this rule seems scarcely applicable. In fact, we have hardly reached the end of the story yet. It is said that the infectious properties of sewage may take effect by means of quantities excessively minute. The exciting cause of infectious disease has been shown to depend on the presence of minute living organisms, similar in their appearance and nature to those which have long been known as the cause of fermentation and decay. In the case of typhoid fever and cholera the action of these organisms has been identified with a fair approximation to certainty. The chemical treatment of this question depends on the circumstance that the micro-organisms have an animal origin. As nitrogen, generally speaking, is more abundant in animal substances than in those of a vegetable nature, it may be considered that when the organic matter in water possesses a large amount of nitrogen in comparison with the carbon, this organic matter is of animal origin. If, at the same time, there is an undue proportion of ammonia and nitric acid, the state of the water becomes still more suspicious. Still, as already indicated, the case is simply one of suspicion, and the question yet remains whether the organic matter is accompanied by the presence of zymotic germs. The argument has much force, that towns ought not to be supplied with water which is subject to animal contamination, seeing that such a supply is liable to become infected with the virus of disease. Suppose the zymotic germs to enter the Thames from a house-boat on the river above the London intakes. Is the metropolis thereby threatened with sickness and death? Theoretically it is so. Practically it may be otherwise. Is all London really at the mercy of a single cluster of germs? Will nothing kill these creatures or impair their vitality? Can they not be arrested on their way, and so be turned aside from their purpose? We are thankful for the statement made at Chatham, that recent investigations carried out by the aid of the gelatine process "have brought to light the remarkable fact that these micro-organisms are by no means so unimpres-

sionable as had previously been imagined." We have seen that filtration arrests them to such an extent that only about one in fifty may be said to escape. If Dr. Koch, or Dr. Percy Frankland, or Dr. Dupré—who has a method of his own—can manage to distinguish between the harmless and the hurtful of these microphytes, positive knowledge of the most valuable kind will be thereby placed at our disposal. Until then we are still in a great measure groping in the dark, though there is a glimmering light ahead which promises to lead us in the right direction. That which we may properly demand is not the unattainable, namely, water that is absolutely pure, but that which is reasonable, or in other words, water which is practically wholesome. It is to the biological examination of water that we have to look for a determination of this question, and we rejoice to find at the close of the Chatham lectures a belief expressed that this new mode of investigating the problem of the water supply is fraught with the probabilities of success.

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## BLOWHOLES IN OPEN-HEARTH STEEL.

By JOHN HEAD.

Paper read before the Iron and Steel Institute.

Although mild steel is gradually displacing the better qualities of iron in the construction of boilers, ships, and bridges, its behavior in certain cases is somewhat puzzling, and has sometimes given rise to much anxiety, fractures having occurred which, up to the present time, have been classed as of a mysterious character. It is the object of this paper to point out one of the defects to which these mysterious fractures may be attributed, and, at the same time, to show how that defect may be avoided in the manufacture of steel. It is fortunate for steel manufacturers that Mr. W. Parker, the chief engineer surveyor of Lloyd's, has not allowed himself to be frightened by the mysterious failures which have occurred in the employment of steel, but, on the contrary, has made searching inquiries in each case brought under his notice; and manufacturers are much indebted to him, and to Mr. J. T. Milton, and to Mr. Stromeyer, also of Lloyd's, for the valuable reports which they have drawn up, and the papers they have written on the subject, copies of some of which were kindly placed at the author's disposal before he undertook to write this paper. Those reports and papers treat of various matters in connection with the employment of steel for the construction of ships, boilers, and engines, and they lay great stress on the danger of working steel at what is termed a blue heat, that is, a heat ranging between a straw color and blue. It would be needless for the author to insist further on that important point, which has been so ably dealt with at the meetings of different institutions, and quite recently at the Institution of Civil Engineers on the reading of a paper by Mr. Stromeyer on the subject. It is quite another matter the author wishes to deal with in this paper, viz., the presence of blowholes in open-hearth steel, by which the strength and reliability of that metal are affected, and the means to be adopted for avoiding them. Blowholes in steel are of two kinds—those due to the contraction of the metal in cooling, and those due to the presence of imprisoned gases in its mass. With care and by the use of proper appliances in casting, the first kind of blowholes may in a great measure be avoided; but, even when present in steel ingots, inasmuch as they form vacuous cavities, the author agrees with the generally accepted theory that they will close upon the steel being subjected to pressure under hammers, presses or mills, provided that air does not reach them before the weld is complete. But with regard to the second kind of blowholes, the case is different; they can only be altered in form, except in so far as they may be got

rid of by being brought to the surface of the metal, by compression while the ingots are being worked up into merchantable form. Supposing an ingot of steel containing gaseous blowholes to be placed under the hammer or mill, the effect of the work done will be to compress the blowholes, except in so far as some of them may be brought to the surface and so be removed; but the others will remain in the finished article, forming points of weakness which will show themselves on testing for tensile strain, particularly when the strain is applied transversely to the direction in which the metal has been worked. In the removal of blowholes—those of the first kind by welding, and those of the second kind by bringing them to the surface of the metal, in working it up into merchantable forms—is to be attributed the improvement in quality which steel is found to acquire by compression after the ingot has been withdrawn from the mould.

It will be understood that the blowholes due to imprisoned gases in steel are in most cases extremely numerous, although minute in size, and they are not uniformly distributed in the ingots. They are similar to the cavities in glass, technically known as seedy boil, which may be seen in the sample bottles, &c., which have been placed on the table, marked as made before the year 1883. Later on reference will again have to be made to glass and its manufacture, as affording a ready means of explaining the manner in which blowholes in steel are produced and may be prevented. During pouring of steel the gases it contains rise to the top of the ingot or casting so long as it is in a sufficiently liquid condition for that purpose. Such upward movement is soon arrested, however, by the metal assuming a plastic condition, but at the top there will always be found a greater number of blowholes than at the bottom, and these will be much larger, as there is little head of metal at that point for compressing them. These blowholes cause the rising or boiling action which has necessitated stoppering moulds with sand and wedge plates; whereas the metal, shrinking on cooling, should, on the contrary, cause the top of the ingot to be depressed, or to take a cup shape. To the presence of gaseous blowholes in steel in greater or less number or size is due the difference in tensile strain which test pieces from the same charge, and frequently from the same plate or bar, withstand. Although this circumstance has not hitherto been remarked upon, it has been admitted and allowed for in practice, for the Admiralty, the Board of Trade, and Lloyd's rules all allow a margin of 4 tons, between 26 and 30 tons, in the tensile strain of boiler plates, per square inch of sectional area, while for ships' plates, Lloyd's rules also allow the same margin of 4 tons between 28 and 32 tons, which represents a range varying to the extent of one-seventh on the minimum strength insisted upon. In his paper, read at the Institute of Naval Architects in March of last year, Mr. Parker said: "This range of about 4 tons in the tensile strength of a plate of homogeneous metal like mild steel is very unsatisfactory." This is the only comment which appears to have been made on this interesting subject.

In explanation of some of the failures in steel which have hitherto been classed as mysterious—no attempts at explaining them having been made—the author would suggest the possibility that in certain cases the gaseous blowholes in an ingot may have sorted or arranged themselves in a series, thus forming a line of weakness in the plate or bar which has failed along that line when subjected to a strain much below that which test-pieces from the same plate or bar would withstand. The failure of the boiler plates described in Mr. Parker's paper previously referred to, read at the Institution of Naval Architects, might be thus explained; and Mr. Cuthill's remarks during the discussion which followed, seem to confirm that conclusion, for he said: "Some of the tests since made of the plate corroborate the original, while others are considerably higher, averaging about 2 tons over it. No explanation can be given as to this, other than that the original was taken from the scrap edges, while the higher ones and better in extension, have been taken from the plate." Other failures in steel have occurred while the metal was being worked up into ships or boilers, which may also be explained by the existence of blowholes, forming a line of weakness in the plates, but not necessarily a straight line.

When the plates were riveted at the ends of the line of blowholes, the tensile strength would not be much affected; but when riveted at the sides, crossways, there would be a certain stress produced which would lead to breaking. These failures are apparently complicated by the circumstance that they occurred when the men were away from their work, either during the dinner hour or at night, but on consideration it will be seen that this circumstance will materially assist in arriving at an explanation, for the rivets, when put in, were in a heated condition, and heated the plate to some extent, thereby causing a certain amount of expansion, which was sufficient to allow for the stress; but on the men ceasing work, cooling took place, stress was put upon the plate, and it snapped across in the line of blowholes, but not necessarily through any rivet-holes.

Speaking of the fractures in the steel plates supplied for the boilers of the Russian yacht Livadia, in their report dated February 16, 1881, Mr. W. Parker and Mr. J. T. Milton say: "It was also suggested that the brittleness might have been induced by the absorption of gases." It is to be regretted that this failure was not inquired into from the point of view here indicated, as such an inquiry could not have failed to elicit valuable information. At some works agitating the molten metal in the ladle before pouring into the moulds is practised for the removal of gases from Bessemer steel. To our past-president, Sir Henry Bessemer, is due the honor of having first suggested that means; and in the year 1881 Mr. W. Allen brought before the meeting of this institute a mechanical agitator which he had used with advantage. In the discussion which followed the reading of Mr. Allen's paper, the late Sir William Siemens spoke of some trials which he had made for poling molten steel in the ladle, in order to remove the gases it contained; but he was evidently aware that all these means were expedients, designed to mitigate a defect in steel manufacture which could not at that time be removed, for he added a remark I shall quote at length later on as bearing pointedly on the subject under consideration. It may be added that at a works where the manufacture of both Bessemer and open-hearth steel is carried on, the latter in furnaces heated by radiation from flame, an agitator is used for Bessemer steel, but is not required for open-hearth steel, which lies quite still in the moulds without having recourse to that means.

It has been supposed that the gases forming blowholes in steel are bubbles of carbonic oxide formed by the reaction of iron oxide on the carbon in the manganiferous iron, added to the molten steel before it is poured into the moulds. This explanation, however, is open to the objection that manganiferous iron, being specifically heavier than steel, sinks immediately to the bottom of the molten metal to which it is added, being only momentarily in contact with the slag on the surface; and, further, that, as already pointed out, we find gaseous blowholes, or seedy boil, in glass, in the manufacture of which the addition of manganiferous iron, or any material containing carbon, at the end of the operation is not practised. If the gaseous blowholes found in open-hearth steel are bubbles of carbonic oxide, hydrogen or air, these gases may have been obtained from those used for melting; and this conclusion is supported by the fact that blowholes or seedy boil are found in glass and steel melted by contact of flame, and are absent when melting without contact of flame is adopted. Diagrams are given, representing, respectively, longitudinal and transverse sections of a plate-glass melting furnace heated by contact of flame—such furnaces as were constructed by Messrs. Sir W. and F. Siemens about the year 1862. In this furnace the flame enters the heating chamber at the level of the siege, and plays around and on the top of the pots, so as to obtain as much contact as possible between the flame and the materials to be heated; after doing its work in the heating-chamber the flame leaves at the end opposite that at which it may happen to enter at the time. In the manufacture of plate-glass in such furnaces, the pots are charged at intervals with the mixture called batch, being filled in the first instance, and refilled each time the materials are melted into glass, and thus diminish considerably in bulk. When the last charge has been melted, the greatest heat possible is put on for abou t

an hour in order to heat the furnace and its contents thoroughly, after which gas is entirely, or nearly entirely, cut off, and the furnace closed, for about four hours, to allow the metal to fine. The fining of metal in this manner is for the purpose of removing seedy boil, or blowholes, the gases forming them rising to the surface during this operation. The fining operation will be completed in about an hour, but as plate-glass is required in a plastic condition, flame is kept out of the furnace for some hours longer before the metal is ready to be cast. The pots themselves, and their contents, are removed for that purpose, if large plates are to be produced; or the metal is ladled out of them when it is only required to produce small articles, such as tiles, ships' lights, &c.

The manufacture of window-glass is carried on in the same manner as plate-glass, so far as regards charging, melting and fining; but as this glass is worked hotter than plate-glass, less time is allowed for cooling before blowing is commenced. Some plate-glass furnaces hold as many as twenty-four and thirty pots, called cisterns, each containing about 12 cwt. of metal, so that each found in the larger furnace will weigh about 18 tons. Window-glass furnaces hold from eight to ten pots, each containing about 3 tons of glass; in bottle-glass furnaces, the pots employed are of smaller capacity than those used for window-glass, each holding about 1¼ ton. In order to remove seedy boil from glass melted by contact of flame, recourse must be had to the method of fining described, that is, the metal must be kept under the influence of heat without contact of flame. The operation will be more or less complete according to the temperature maintained in the furnace after the flame has been cut off, and the time which can be allowed for the glass to settle. In the manufacture of common bottles, cheapness of production rather than good quality of glass, having, until recently, been the object aimed at, the glass made, as shown by the bottles exhibited, contained much seedy boil. In order to reduce the cost of production, and at the same time improve the quality, Mr. Frederick Siemens some years since invented the continuous glass melting process, which is adopted by all the leading bottle-makers in England and on the Continent, and is now being largely introduced for making window-glass. Since the introduction of this process, bottle-glass furnaces have been enormously increased both in their holding and working capacity. Up to 1882 the largest furnace of this kind was one of those built in England, the tank measuring 42 feet long by 16 feet wide, and holding about 150 tons of metal; but in combination with his new method of heating by radiation, Mr. Siemens, at Dresden, has been able to augment considerably the capacity of these furnaces, and a photograph is placed before the meeting of a circular furnace at his works measuring about 40 feet diameter, and holding about 230 tons of glass in fusion.

Diagrams are also given showing, respectively, longitudinal and transverse sections of a tank glass furnace heated by contact of flame, these diagrams being taken from the drawings of a furnace similar to that just referred to as holding 150 tons of glass. The flame is made to strike on to the metal in fusion, with the result that the glass made contained some seedy boil; but the glass produced in this furnace being better than that made in the furnaces which is superseded, no notice was taken of the circumstance at that time. As bottle-glass blowers commence work each week on Monday morning at six o'clock, and leave off work about the same time on Saturday morning, that day is available for cleaning the flues, during which operation the glass in the tank is partly refined, as already explained, further fining occurring on Sunday, when the furnace, not receiving any addition of fresh batch, gas and air have to be partly cut off, to reduce the heat, and under these conditions the flame would not come into contact with the metal in the tank. Thus a certain amount of refining was always practised in making glass by the continuous melting process, and, when necessary, the tank could be treated as a huge pot, all the heat possible being applied for some time, after which, the furnace doors and openings being closed, the flame would be reduced for a few hours by shutting off nearly all the gas and air. On one occasion the author dealt with a large tank furnace in that manner, and, as was expected, the metal

was found afterwards to be of excellent quality and free from seedy boil, or blowholes. By the adoption of Mr. Siemens' new method of heating furnaces by radiation, the loss of time and fuel consequent on fining when pot furnaces are employed is avoided, and seedy boil has disappeared in glass made by his continuous melting process. The presence of seedy boil in glass is therefore attributable to the contact of flame with materials in fusion, and is avoided when glass is melted by radiation from flame. The same result is obtained when glass is melted in closed pots; this is another but rather expensive way of avoiding contact of flame with materials in fusion, which in glass-making can only be adopted for the best qualities of glass, table glass for instance. Samples of glass melted under these conditions are exhibited, and will be found to be quite free from seedy boil.

A good form of furnace for melting glass continuously is shown by two diagrams, one being a longitudinal section, the other a sectional plan. The gas and air enter into combustion at a certain distance above the metal in the tank, and the roof and walls are so arranged that the flame does not touch them, but sweeps round the heating chamber, in horse-shoe form, to the exit on the same side of the chamber as the admission ports. For the manufacture of glass this form of furnace offers many advantages, as, while providing a long run for flame, thus promoting perfect combustion, it gives a large extent of surface at which the workmen may be placed for gathering and working. This same form of furnace has also been adopted with advantage for melting steel on the open-hearth; or long furnaces, holding 40 to 50 tons of steel are used, in which case they are made fish-bellied in plan, so as to allow space for lateral expansion, as well as a long run for the flame. In Mr. Siemens' furnaces at Dresden, before referred to, the run of flame from the inlet to the outlet ports is nearly 100 feet, and the greatest uniformity of heat is thereby secured, combined with economy in working. It has been shown that seedy boil or gaseous blowholes are invariably found in glass when made in furnaces in which contact of the flame with the materials in fusion occurs, and it has been shown also that these defects may be removed by fining, or may be altogether prevented by melting glass without contact of flame—that is, in closed pots, or by radiant heat. The same remarks hold good with regard to steel. What is wanted at the end of the operation is that the fused metal should lie quiescent for a certain length of time under the influence of intense surface heat without contact of flame. In glass-making, seedy boil may be obviated in two ways—either by fining, as has been explained, or by melting without contact of flame, but for making steel on the open-hearth the latter alternative is alone practicable, for the reason that it is required to be tapped as hot as possible, whereas glass is worked in a semi-plastic condition.

The desirability of maintaining steel in a quiescent state for some time before pouring was recognized by the late Sir William Siemens, who, after describing the trials he had made of poling steel in the ladle, before referred to, made the following prescient remarks: "I have observed that considerable benefit accrues to the steel if, after it has been poured into the ladle, it is allowed to remain there under the protecting covering of slag to prevent decrease of temperature." The objection to this mode of proceeding is that, at this portion of the process, time is valuable; but I feel sure that practical benefit will accrue if the steel can be kept in a quiescent fluid state for a quarter of an hour before pouring. Of course, it would not do to leave steel for a quarter of an hour in the ladle; it would partly set, or become plastic if that were done; and Sir William Siemens referred to that circumstance when speaking of time being valuable at that part of the operation. In 1881 all furnaces were heated by contact of flame, but his genius enabled Sir William Siemens to forecast the requirements of steel manufacture to render the operation perfect. Mr. Frederick Siemens had not then invented his new method of heating by radiation, and had Sir William Siemens been spared to us a few years longer he would have been pleased to find in the application of this invention the solution of the remaining difficulty in steel manufacture.

There is another point to which, before concluding, I wish to draw your at-

tention, at least briefly, viz., the analogy which exists between glass and the slag covering steel in open-hearth furnaces. If the slag were deprived of most of its iron, it would become clear glass, hence the method of fining applied to glass-making will also apply to slag in steel-making. In the early days of the open-hearth steel manufacture, glass was proposed as a protective covering for steel to prevent flame from penetrating to the molten metal beneath, and the slag floating on steel is perhaps even now looked upon as affording such protection. The behavior of glass when melted by contact of flame will not, however, as has been shown, sustain that opinion. In bringing to bear upon the subject of steel-making the results of experience obtained in another manufacture, members will understand that the author is dealing with figures worthy of their attention, the quantities of glass treated in continuous glass-melting furnaces varying between 80 and 230 tons at a time, and so far as the dimensions of these furnaces are concerned, it need only be said that they much exceed anything as yet employed in steel-making. This will become evident when we consider that the tank furnace described, which is one of many built in England, would hold 375 tons of steel, and the furnace described as built at Dresden—Mr. Siemens having several furnaces of the same size in operation—would hold 575 tons of steel, the densities of steel and glass being taken as 7 and 2.8 respectively. There can be no doubt that by manufacturing open-hearth steel free from gaseous blowholes the metal produced will be much stronger and more reliable than that made by contact with flame, and the result will be a greater confidence in its use. The merit and utility of Mr. Siemens' new method of heating by radiation, by which this may be effected are enhanced by the consideration that the production of steel of superior quality by its means is attended with considerable saving in cost of construction, in wear and tear of furnaces, and in waste of metal, the yield of sound bars or plates from a given weight of ingots being considerably more than was attainable with steel melted by contact with flame.

Mr. Aitken said he had given considerable attention to the subject of gases in metals, and had spent many thousands of pounds in experimenting, but had obtained no commercial results beyond a slight increase of knowledge. It occurred to him that the difficulty resulting from gases in steel might be dealt with by mechanical means. No doubt, as the paper pointed out, if iron and steel could be dealt with in the same way as glass was dealt with in Mr. Siemens' furnaces, and kept hot for a long time, the gas in the metal would to a large extent be got rid of, and a sounder ingot would be obtained. Moreover, these metals were very much more expensive than they would be if any practical method of freeing gases from metals by mechanical means could be adopted. Mr. Aitken then referred to a diagram in which he suggested one of the modes by which this object could be attained. They had now taken up the subject again, because he thought the time had now arrived when the subject was rife for discussion. Seven years ago he took out a patent for a mechanical means of freeing gases from metals, but he had been able to do nothing with it, because it seemed that the question was not ripe. The diagram represented a ladle filled with molten metal. The exhaust chamber was lowered from the top and the nozzle projected into the upper part of the metal. The vacuum was then applied, and four tons of metal were drawn up into the vacuum chamber. When Sir Henry Bessemer made some experiments he took a pot of molten steel from the Bessemer converter and poured it into a crucible, and he put that under a vacuum. As a result, when the vacuum was applied the metal swelled and almost exploded, and there was only one-third of it left in the pot. Therefore when the metal was drawn by the vacuum into the vacuum chamber he expected that a very large expansion of metal would take place. When one charge was done the air would be admitted again, and the metal would fall back into the ladle. It was found that metal treated in that way was of somewhat higher specific gravity. Having lost a certain amount of gas the metal was more dense, and the gases in escaping had also absorbed a certain amount of heat. The denser metal would be found to settle at the bottom, and by successive changes it would be possible

to free the whole of the steel in the ladle from the gases. Then the question arose, What would be the effect of that? His own impression was that steel would be very much strengthened by the extraction of the gases, and if this plan were adapted to the Bessemer process he thought the use of spiegeleisen might be done away with.

Mr. Walker regretted that a man like Mr. Head, with his extensive experience of steel, should have put before the institute the words, puzzling and mysterious, in reference to steel. There was no such thing as mystery and no puzzle about it at all. When there was anything wrong with the steel it was because it had been badly manufactured and badly heated. Men accustomed to use both steel and iron knew that there were ten times as many wasters in iron as in steel. If an iron plate had a hole in it that you could put your knife in it was sent back and nothing was said about it, but if the same thing occurred with steel, it would be said there was a mystery as to the cause of the failure. Just as the workmen increased in skill would the number of waster plates decrease. There was no comparison at all between the qualities of steel and iron, because shapes could be moulded in the former metal which could not be made in iron at all. The case of the plate referred to by Mr. Head was not, he thought, due to blowholes, but to want of work. It was not well made. He himself paid particular attention to the matter, and went over to Cammell's at the time. There was no mystery about it, but it was as plain as a pikestaff how the defect came about. With reference to the apparatus which Sir Henry Bessemer had suggested for fusing the metal, its use was quite the exception, and there were very few people who did that. As good steel as he had ever seen had been made in the Bessemer furnace.

Mr. Windsor Richards said he had had a good deal of experience during the last year in making soft steel plates, and had experienced a good deal of difficulty and trouble from two causes, one being the blowholes, and the second and greatest, the irregular distribution of carbon in steel. At Eston they operated on large ingots weighing about 4 tons, 6 feet long, 36 inches wide, and 66 inches thick. Mr. Head had very carefully checked the chemist's analysis, and the carbon in the steel was found to vary from 0.10 to 0.15. The great trouble when ingots had to be rolled was to keep within the limits required by Lloyd's—about 4 tons. Very many things had been tried to get over this serious difficulty, the mechanical agitator, as suggested by Sir Henry Bessemer, and poling the molten lead with a very long pole, as suggested by Sir William Siemens, the latter being more comical than effectual. They also allowed the metal to rest in the convertors for half an hour before pouring, but that did not do, and none of the things they tried were of any avail. At last they tried what had been done at other places, though he thought not for the same reason. Mr. Riley, of the Steel Company of Scotland, poured the metal from one ladle to another, and he thought if he could, after putting the ferro-manganese into the ladle, pour the metal from one ladle to another, he would get rid of the gas, and get a more equal distribution of the carbon. He was glad to say that this method had been very effectual indeed. He would suggest to those experiencing a difficulty to try the process in operation at his own works.

Mr. James Riley said he was very pleased Mr. Richards had made that last statement. He was going to call attention to the fact that steel made in furnaces in which there was contact with the flame was not all of the character described by Mr. Head. Those of the members who last autumn visited the works of the Steel Company of Scotland would, no doubt, remember that the ingots were not stoppered—not at the Newton works, at all events. On any day they pleased they could see the same thing done with regularity and consistency. So dead was the metal, and so free from the gases upon which Mr. Head had dilated, that there was no necessity for the stoppering. That being so, he did not think there was any necessity to found a theory as to mysterious failures and mysterious qualities such as Mr. Head had brought forward, attributing them to them to the presence of blowholes in the steel. He did not believe it for one moment. At the meeting of a kindred institution (the Institution

of Naval Architects) a fortnight or three weeks ago there was something like an apotheosis of steel. There seemed to be a general consensus of opinion that now at last we might take it for granted that we sufficiently understood the metal, and that henceforth there was to be no serious anxiety so long as steelmakers would properly look after their manufacture. It was astonishing, therefore, to come here now and listen to a paper which raised again the bogey of the unsatisfactory nature of steel. Without referring at greater length to that, perhaps he might be allowed to mention a little circumstance which had been known to him for a long time, but which he had not before referred to, because he was rather afraid of communicating too much information, which at times had been turned upon them rather unexpectedly. These mysterious failures were not due to the causes alleged by Mr. Head, but too often they were due, as he thought Mr. Richards was going to explain in his remarks, to the irregularity of the composition of the ingot in different parts. Mr. Richards referred to a variation in carbon amounting to 0.10 or 0.15, but perhaps it might astonish them to know that not infrequently there was a difference of nearly $\frac{1}{2}$ per cent. of carbon in an ingot. It was well enough known to many gentlemen present how that arose. It was a difficulty which had to be met and faced, whether known or unknown to those who were manipulating steel. So surely as that was ignored, so surely were steelmakers landed in difficulties sooner or later with the material they sent out of their works. He believed it was impossible to cast a large mass of steel, so far, at all events, as the heavier ingots were concerned. It was impossible to cast the very heavy ingots which were sometimes made of a uniform character throughout. It was a well-known fact, and had been stated once before, some years ago, at one of the discussions of this institute. But the same thing obtained in the comparatively smaller ingots which they were all dealing with every day. To get over that, to a certain extent he adopted the plan of pouring from one ladle to the other, as Mr. Richards had mentioned, and whenever he called upon his people to make steel of great regularity for certain definite specific purposes, of greater regularity, that was to say, than ordinary. They might depend upon it that if steel would be made where steel could be dealt with, by means of two ladles, a greater uniformity and a better result would invariably be found. This matter of the liquation of carbons and phosphorus and these other component parts was a very serious one, and it was this knowledge which had led him to advise Mr. Parker time after time to keep down the size of the boiler and other plates, and not to let them go to such an extreme as there was a tendency towards. Some might understand why he could not before put this matter forth explicitly. It would be kept back, but he had known of it and carefully guarded against it. This irregularity was mostly found in the upper portions of the ingot. Remove that upper portion of the ingot and get rid of these inequalities, and the material would be very much better than was ordinarily the case.

Mr. Parker said he was very pleased to hear what Mr. Riley had said. They had been endeavoring to discover where plates had failed for a very long time, and he thought this was the first time they had heard a steelmaker speak out frankly. They would all admit—at all events they did at Lloyd's—that the steelmakers should know a great deal more about it than the surveyors, and the latter had done all sorts of things in order to try and draw them to a special declaration. He noticed that his name was associated with the paper, but though that was the case it must not be considered that he agreed in the conclusions come to by Mr. Head, as to the cause of the fractures in steel plates. He would not attempt to deal with his theory as to whether making steel and making glass were analogous; but he would endeavor to deal with the practical investigations which he had made into the cause of the fractures. He would not trouble them with a long history, because he had the pleasure of giving the result of his investigations before a meeting of the Institution of Civil Engineers a few months ago, and it could be found in their *Transactions*. It had been his privilege to investigate every accident of a serious nature that had taken place in marine boiler making, and in every in-

stance the cause had been clearly traced to manipulation and not to any inherent defect in the material itself. Mr. Head had gone back to failures that took place so late as 1881, and these, as I said the other night, were thoroughly cleared up, and they had nothing whatever to do with the blowholes in the castings. As a proof of this he would mention that the plates which gave way were supposed to be brittle, but pieces broken from the exact part that gave way from the exact fracture were found to have the usual amount of ductility. Again, if they took a plate that was rendered brittle by throwing straines upon it, either by shearing it, or punching it, or distorting it, or torturing it in some way or another, and made it red hot and allowed it to cool, the whole of its strength was restored, but he failed to see how making the plate hot and allowing it to cool could take away any blowhole or air bubble. No one regretted Mr. Windsor Richards' difficulty more than he himself did, but he was quite satisfied it did not arise because there were blowholes or seedy boils in the plate. It was his privilege to investigate a plate which Mr. Richards made, and this was the first opportunity he had had of explaining the conclusions he had come to. This plate was fitted into a large marine boiler, and as the boiler was being tested to 180 lbs. pressure, the plate suddenly gave way at 110 lbs. pressure, which was, roughly speaking, one-fourth of its strength. He took that plate out of the boiler, and tested it, and found it had a tensile strength of from 28 to 30 tons, a stretch of 25 per cent. in a length of 8 inches; and it bent double cold, proving clearly, to his mind, that there had been some strain set up in the plate by working it in some way. He pursued the investigation further, and analysed the plate, and it was found to be perfect, so far as the material was concerned. He had no hesitation in saying that the plate, when it left the works of Messrs. Bolckow, Vaughan & Co., was as good a plate as could be made; but still it gave way. Now, on looking at a number of plates at the same works and in other works which his duties required him to visit, he found that steelmakers were in the habit of making very long and very large plates. Some of these plates were 20 feet long, and 4 feet or 5 feet wide, and the majority were rolled to the form of the boiler. In a great number of these plates he noticed that, instead of being perfectly straight and flat, there were little hillocks, showing that the center of the plate was longer than the edge of the plate. In that condition they were sent cold through vertical rolls, and they came out perfectly straight. The inequalities were crushed into the sides of the plates, and that was sufficient to cause them to break even without pressure. That was all he had to say in regard to some of these fractures; but he wished it to be understood that never in his experience had fractures taken place because there had been gas or seedy boils in the plates. In concluding his remarks, he would like to say that the shipowning world generally recognized—though, perhaps, this institute did not know it—that the introduction of steel for marine boiler purposes had been the greatest boon that steamship owners had had for the last fifteen years. It was admitted that the pressures had been increased from 70 lbs. or 80 lbs. per square inch to 150 lbs. or 170 lbs., and it had given to the owners a reduction of 20 per cent. in coal. Without this material they could not have done that with the present form of boiler. Half a million of money had been spent in trying to introduce a different description of boiler in order to get at that pressure within the last ten years, but all attempts had signally failed; but steel had given to engineers a boiler which could be worked at 150 lbs. or 170 lbs., and an engine had been introduced which could economically use that steel. A shipowner could therefore sail his ship at 20 per cent. less cost, so far as coals were concerned than he could ten years ago. To his mind this was the greatest stride that had been made in marine engineering since the introduction of the compound engine, and it was entirely due to steel. There had been little failures and little fractures, and they had endeavored to grapple with and get to the bottom of them. To show to what extent this material had been appreciated and used, he might say that not one out of a hundred boilers that came before them (Lloyd's) was made of iron, and from 1878, when he had the honor of reading his first paper on this subject

before the Institute of Naval Architects, down to the present time, he found that 160,000 tons of this material had been put into boilers for the mercantile marine of this country.

Mr. Martell felt, with Mr. Riley, considerable surprise that at the present time, after the great experience they had had with mild steel, a gentleman intimately connected with the manufacture of it should come before the institute and speak again about the mysterious fractures that were so much referred to in former times. A gentleman connected with the firm of Denny & Co., who had built a great number of ships, stated at the meeting of the Institute of Naval Architects that among the thousands of pieces of mild steel they had used within the last few years in the construction of ships, the failures could almost be counted on the fingers. Who could talk about uncertainty when such regularity as that was ensured? He had no hesitation in saying that when the material was carefully manufactured and passed the required tests it might be used with the greatest confidence. There was no necessity to assign any cause for the "mysteries," because they did not exist nowadays. He hoped the day might very soon arrive when mild steel would entirely supersede iron in the construction of ships for the mercantile marine of this country.

Mr. E. A. Cowper said he quite agreed that very long plates should not be used in marine boilers, because there was a greater chance of variation of quality. If one plate harder than another were placed alongside that other, the strain must come upon the stiffest plate of the two when the ship got upon the rocks. He thought that in Mr. Frederick Siemens' furnace the higher roof allowing the products of combustion to form a flame clear of the roof as far as possible was a most distinct improvement. It saved the furnace, it gave a higher temperature, it saved the fuel, and it gave a better product. There was no occasion to go into a number of theories about blowholes, because if the metal was made hotter and kept quiet, those bubbles would go out.

Mr. Greig said he had made 20,000 boilers, and his experience of steel was that it was twice as good as Low Moor under any circumstances. The cracking was due to the ignorance of the manufacturer, as a general rule. He believed in drilling holes, and it was simply nonsense to say that the stuff would not stand it. He would prefer drilling the plate in order to get to know the material, because if he was taken with his eyes shut through a boiler shop he could tell whether the material was right by hearing the punching going on. That was sufficient to indicate whether there was too much carbon, and whether the plate was too hard or not.

Sir Nathaniel Barnaby said that the question between steel plates and iron plates had been thoroughly settled for a long time. The importance of the paper rather pointed to the controversy between the steelmaker and the forgeman. Those who were concerned in shipbuilding and were interested in the change that was rapidly taking place in the use of castings instead of forgings, had found that a great many difficulties arose from the want of soundness in casting. He had had the advantage of seeing in Mr. Roach's shop in New York a steel shaft which had been made for a ship of war called the Dolphin. It had been hammered down to half its size, but when it was put in the ship and tried it broke. Just in the center of the plate there were two large fissures crossing each other. If it should appear that there was any advantage in the new method by which greater soundness could be procured in the castings, he thought steelmakers would not consult their true interests if they contented themselves with saying that they had had great success in making splendid steel plates for ships and boilers. They ought not to be satisfied until they could make thoroughly sound castings, and when they accomplished that the day of the forgeman would be over, and the sooner the better.

Mr. E. O. Harvey said that during the last few years he had had opportunities of comparing the work of the contact furnace with the radiator furnace. At some works he had had them side by side, and in every case for tinplate metal, for boiler plates, and for castings, Mr. Frederick Siemens' radiator furnace gave distinctly better results. The gases did

not play on to the metal, and were not absorbed, and there seemed to be more diffusion of the heat, which caused the metal to cast sounder in the ingot. It had been said that sufficient heat could not be attained, but his experience was just the opposite. He had always found that when there was not sufficient heat it was due to the bad construction of the furnace. With the new radiation furnaces there had been produced regularly at the works he had been at, eleven, twelve, and thirteen charges of tinplate metal per week, with carbon of from 0.11 to 0.14; and in making steel castings he had been able, in many instances to go sixteen, eighteen, or twenty minutes during the casting operation, and still have no skull in the ladle. That spoke amply for the heat which could be obtained in those furnaces. He had tried Sir William Siemens' suggestion to keep the metal in the ladle some time before casting, and he found that it was cogged down better. He also tried another experiment. Instead of keeping it in the ladle a minute or two before pouring he turned off a certain amount of gas in the furnace, and the result was very similar. It behoved every manufacturer to look into this, and adopt that form of furnace which would give the best soundness. With regard to the absorption of sulphur which sometimes took place from the gases which were passing over the metal in an open-hearth furnace, some time ago he tried experiments in ordinary steels varying from 0.3 to 0.6 of carbon, and there seemed to be more sulphur come out in the ingot than he could calculate in the mixture, even allowing for a certain amount of waste by oxidation which always took place in the Siemens's furnace. In a recent report from Olsberg it was stated as proved in Sweden that the sulphur was appreciably attracted to the metal or absorbed in it by the gas passing over it in an open-hearth furnace when in direct contact with the flame. From a considerable number of experiments there appeared to be an absorption of from 0.015 to 0.025 of sulphur due to that cause entirely, and sometimes as much as 0.3 per cent., but it was said that when three kilogrammes of lime were added to 43 kilogrammes of coal in the gas producers, the absorption of sulphur could not be so traced; it was either very much less or there was none at all. He mentioned this because in a furnace like Mr. Siemens' new form it was very probable that there would not be this absorption of sulphur which had been noticed in the old furnaces where the flame played upon the metal.

The president asked Mr. Ellis if he had tested the merit of his invention for keeping the top of the ingot mold highly heated for a long while, with a view of giving time for a more thorough elimination of the bubbles of gas.

Mr. Ellis said he had found that by using a clay top, and keeping it hot, he could to a great extent keep the metal at the top hot so as to allow the gases to escape and the metal to settle more soundly, but there were several difficulties connected with keeping the clay top sufficiently hot, and by using a different method he could obtain the soundness on the top of the ingot in another way.

Mr. J. Hardisty said that the production of small steel castings was still a somewhat difficult problem, but with large castings there was no difficulty whatever. 0.08 of silicon could be safely put in an ingot without interfering with the ductility of the metal.

Mr. John Head, in reply, said it was evident that the users of steel were far more in love with it than the producers. The users thought there was no fault whatever to be found with it, but makers of steel were conscious that there were little points which might be improved upon. This showed that manufacturers of steel had delivered a constantly improving article to the users. He thought that Sir N. Barnaby could not have read the paper, for it made no allusion whatever to iron. It spoke only of steel and glass, and he had tried to bring his experience in connection with glass to bear on the manufacture of steel. Glass was a transparent article, and enabled them to see what they could not see in steel. He inferred that the improvement in glass made without contact with flame might to some extent be made in steel by using furnaces which prevented the contact of the flame with the ingot. Still, prevention is better than cure, and if they could avoid the blowholes in steel it would be better than merely keeping

away the gases which formed the blow-holes in cooling. In addition to that there was the advantage of preventing the addition of sulphur. It had been generally supposed that for making very mild metal silicon was not a very desirable material, and it was not generally used.

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## THE EFFLUENT FROM THE BERLIN SEWAGE-IRRIGATION WORKS

By PROF. DR. ALEXANDER MULLER.

From "Gesundheits-Ingenieur."

The surface at present under irrigation comprises two districts north and south of the city, with a total area of about 5,000 hectares (12,355.7 acres). The drainage of these districts is discharged into numerous small streams, all of which are tributaries of the Spree. The drainage of the north-eastern districts passes chiefly into the Wuhle, and that of the north-western area into the Panke, while the southern effluent is nearly all carried into the Havel. Owing to the non-completion of the irrigation-works, and the rapid manner in which the drainage of the town was carried out, the northern area was almost constantly flooded, and speedily got into a very bad and swampy condition. Owing to this the effluent was very impure, and it was feared that, partly by means of the water supply derived from the Spree, and partly by the ice, the inhabitants of Berlin might have the indirect enjoyment of their own sewage. This unfortunate state of things at length induced the Government to undertake searching tests, and to frame stringent enactments. Moreover, some of the adjoining owners of land invoked the aid of the law to defend their interests.

The results are here given of the examination of certain test-samples taken from the Panke in 1883, in order to ascertain to what extent the drainage from the irrigation-works had an injurious effect upon the water of that river for bathing purposes. The samples were three in number, and were taken from various parts of the Panke. The first sample, A, was quite clear and bright, but had a yellowish tinge when seen in a glass vessel; the second, B, was greenish in color; the third sample, C, taken lower down the stream, more resembled sample A. The microscopic examination corresponded with the appearances above noted. A showed, after standing, only a slight brownish sediment, containing desmids and bacilli, together with a little humus matter. B, a copious, rapidly-increasing, light grayish-green sediment, consisting of different species of desmids and infusoria, together with varieties of leptothrix, that is to say, of such organisms as are regularly to be found in polluted waters, towards the close of the period of self-purification. C presented the appearance of a strongly diluted variety of B.

On making a chemical examination of these samples, it was found that A, which represented the river in its natural condition, was fairly pure, and quite fitted for bathing purposes, notwithstanding its somewhat high percentage of humus. Attention is called to the marvelous self-cleansing power which the River Panke possesses; for while at Bernau (where in summer time there is very little water) the smell and appearance is pestilential in the extreme, in a distance of less than two kilometers, after flowing sluggishly through the market-gardens and meadows, it again presents a wholly innocent and unpolluted character.

Sample B bore signs of being an effluent from the subsoil in the last stage of self-purification.

Sample C might be regarded as a passable bathing water. Details of the analyses of the 1883 specimensare given.

It is also pointed out that in periods of drought, while the irrigation goes on at the usual rate, the volume of the water in the river rapidly diminishes, and the relative proportion of river water to effluent undergoes a great change. More-

over, it has been noticed that from time to time large quantities of untreated sewage find their way into the Panke.

The results of a second examination of the water in the year 1884, which are then given, are very similar to those already quoted. Detailed analyses of the original river water, represented by sample A, and of the effluent represented by B, are given as follows:

| | Constituents in parts per million. A. | B. |
|---|---|---|
| Oxide of iron and alumina | 0.5 | 2.4 |
| Lime | 97.5 | 220.3 |
| Magnesia | 8.9 | 18.9 |
| Potash | 3.4 | 6.5 |
| Soda | 14.2 | 99.3 |
| Chlorine | 17.5 | 139.2 |
| Sulphuric acid | 12.1 | 75.5 |
| Nitric acid | .. | 63.0 |
| Silicic acid | 9.0 | 12.2 |
| Carbonic acid (calculated) | 80.3 | 114.0 |
| Total | 243.7 | 751.3 |
| Deduct for oxygen replaced by chlorine | 4.0 | 31.4 |
| Total | 239.7 | 719.9 |

Or by arranging the acids and bases, excluding the indifferent silicic acid and the oxides of iron and illumina, the following distribution may be assumed:

| | A. | B. |
|---|---|---|
| Silicic acid | 9.0 | 12.2 |
| Oxide of iron and aluminium. | 0.5 | 2.4 |
| Carbonate of lime | 160.4 | 213.0 |
| Sulphate of lime | 18.2 | 128.4 |
| Nitrate of lime | .. | 95.7 |
| Chloride of calcium | .. | 30.0 |
| Carbonate of magnesia | 18.5 | 39.5 |
| Chloride of sodium | 26.8 | 187.4 |
| Chloride of potassium | 3.1 | 10.3 |
| Sulphate of potash | 2.7 | .. |
| Total | 239.2 | 718.9 |

As a general result of the investigations, it is pointed out that the orignal river water is as pure in 1884 as it was in 1883; that the drainage from the irrigation works remains equally unaltered; and that the pollution of the river has been traced over the same area as before; that the clarified effluent from the irrigation works, however, is much inferior in quality to the original river water, and in times of epidemics must be regarded with suspicion.

## ON A GEODETIC SURVEY OF THE UNITED STATES.

By C. O. BOUTELLE.

From "Science."

I HAVE been often asked why a geodetic survey and triangulation is the only mode of surveying a large area with precision, and why such slow and tedious methods are requisite for needful accuracy. This paper is an attempt to show in popular language, both the processes themselves and their necessity, as also why Congress should act upon the repeated recommendations of the National Academy, and carry out its views.

To many of the habitual readers of *Science*, this letter will appear to deal with elementary matters which they may be assumed to know. To another large and equally earnest class of readers it may convey useful information. Possibly it may help forward the end sought for, and to this every true lover of science will cry "God speed."

Any survey of a small area, as a farm, plantation, or township, may be made by any of the usual methods adopted in ordinary land-surveying, where the area covered by the survey is treated as a plane surface.

The compass and Gunter's chain of sixty-six feet are the usual surveying instruments in this country. They are liable to serious error. Lack of knowledge of the true local magnetic variation of its secular change from year to year, and of its diurnal change between morning and afternoon, with the always impending possibilities of special local attraction at or near the place surveyed are among the difficulties attending the use of the compass. The chain stretches with use, and changes its length with the seasons and their varying temperatures, and is often carelessly carried by men little accustomed to precise methods.

It is not too much to say that any land worth fifty dollars an acre is too valuable to be surveyed with a compass, and any record of such a survey is likely to become a fruitful source of future litigation. The best of such surveys are but approximations to the truth.

Errors from these approximate measurements are cumulative. When such surveys are extended over large areas, as upon our public lands, serious consequences follow, involving present and future doubt and litigation as to boundaries. This is already apparent in the west. It will become more so in the future as land increases in value.

The necessity for greater precision in original public-land surveys, and for means of ascertaining and checking errors already existing, has been forcibly stated in a report to Congress on the survey of the Territories, by the National Academy of Sciences, in November, 1878, printed in "Misc. doc. No. 5, House of Representatives, 45th Congress, 3d session." The report of the academy, and the very strong letter of Major J. W. Powell, which forms a part of it, fully describe the character and consequences of the errors alluded to. It also sets forth the true remedy as only to be found in a method of survey which should be as nearly infallible as scientific skill and a laborious and careful application of well-known principles could make it.

This method, as practised for two centuries by civilized nations, consists of a system of triangles starting from and proceeding toward certain base lines, measured with every possible care with apparatus specially devised to either entirely eliminate or to reduce to a minimum every source of error, whether physical or mechanical, which might vitiate the resulting length of the measured line, or cast a doubt upon its precision.

Apparatus of this nature is now constructed and used in the U. S. Coast and Geodetic Survey, of such precision that the average probable error of the two primary bases last measured with different apparatus, constructed on different principles, is, roughly, about one twelve-hundred-thousandth part of the lengths of the measured lines.

The exact length of the base being ascertained, and a system of triangles built upon it adapted to and covering the country to be surveyed, the lengths of all the other sides of the triangles in the system are inferred from the familiar theorem that "every triangle has six elements or functions, viz., three sides and three angles, any three of which being known (one being a side), the other unknown elements may be computed" with a degree of precision of the same order as that of the known elements. It is therefore only necessary to measure the angles with the same precision as the base, to insure equally precise results. This is so far attainable, that the latest great primary triangulation of the coast and geodetic survey, enclosed between two measured bases six hundred miles apart, met nearly midway, at a line about twenty-nine miles and a-half long. The computed lengths of the line, from measured bases distant about three hundred miles from either of them, agreed within about five-eighths of an inch.

It follows from the above, that, in any system of triangulation carefully conducted, the relation of every point in the system to every other point may be determined with a degree of precision almost absolute. It renders the position of each apex of a triangle infallible, since its error, if any, can only be detected by application of similar methods of precision, which will themselves be liable to the same sources of error.

Referring to what has been written as to cumulative errors belonging to all ordinary local topographical or other surveys, it is evident that, if these surveys include two or more trigonometrical points within their limits, the inevitable error involved in their methods is checked and corrected as each such point is successively reached. If it is not exactly hit, the local survey is wrong, and must be corrected to meet the triangulation point, which stands as infallible in its assigned position as the Pope claims to be in his.

The triangulation gives the relation of every point in the system to every other point. To apply the data thus obtained to its chief use in the construction of accurate maps, from the local surveys thus checked and corrected, another class of observations and reductions becomes necessary to fit the framework which has

been constructed to its proper place upon the surface of the earth. This, with the triangulation, constitutes what may properly be called geodesy. No better definition of this term can be given than that by the late General R. D. Cutts: "Geodesy, in practice, may be described as a system of the most exact land measurements, extended in the form of a triangulation over a large area, controlled in its relation to the meridian by astronomical azimuths, computed by formulæ based on the dimensions of the [adopted] spheroid, and placed in its true position on the surface of the earth by astronomical latitudes and differences of longitude from an established meridian."

The whole system of triangulation thus combined and co-ordinated, and made to occupy its true position upon the earth's surface, may be compared to a human skeleton. As the skeleton is the framework on which is built and sustained the varied elements of the human body, each fitted to and held in its place by the unyielding structure sustaining it, so the triangulation is the framework on which each varied portion of the earth's surface within its range is also fitted to and held in its true position, and the resulting map becomes an absolutely true topographical picture of the country it purports to represent.

But this is only one, and not the greatest, good represented by a well-executed and complete geodetic survey. Every point of the triangulation is carefully marked above and beneath the surface for reference in future ages. Every recorded distance between any two points thus marked becomes a base line, whose length is known with a degree of precision unattainable by ordinary methods. So, also, is the azimuth or angle with the true meridian made by every such line, thus affording means for ascertaining the local magnetic variation and its yearly change. The recorded and published latitude and longitude of any station will enable future astronomers to find close at hand the means of fixing their precise relations to other and distant observatories. As the country increases in population and wealth, its topographical features change. New towns are built, and new roads and new railroads laid out. New maps will be called for and easily supplied, since the framework of the triangulation, executed half a century before, perhaps, is there, always correct and reliable. As the elevations of all the stations above the mean level of the sea have been determined in the original survey, so, if schemes of drainage are planned to bring swamp lands into use for arable purposes, these differences of level will afford data for obtaining the amount of fall and its proper direction. And so long as the earth and sea maintain their relative positions, so long the beneficent effect of early and exact triangulation will continue to be felt.

This is essentially a national work. It cannot be defined by, or confined within, State boundaries. Whatever views may be held as to local topographical surveys, and who shall execute them, it is evident that the framework on which they are to be built must be independent of political boundaries. The triangle sides leap across bays and lakes, or from mountain to mountain and hill to hill, or they travel "upon stilts" across the level swamps and prairies. Nature only fixes its limits. It is homogeneous and universal by its own conditions of existence. The geodetic survey of all our country is therefore a work eminently proper for the national Government to carry on, leaving the other questions of local topographical surveys for national or State action, or for both combined, as in Massachusetts.

The National Academy of Sciences, which is by law the adviser of Congress and the executive upon scientific matters, has twice, at the call of Congress, advised the early execution of this great work, and that its execution should be intrusted to the Coast and Geodetic Survey, as best fitted in men, means, and training, to carry it on. Lately the need of prompt action in the same direction has been well and strongly set forth by Prof. W. P. Trowbridge, of Columbia College, whose large experience gives weight to his words.

If States whose interests require good maps will join with commercial bodies and scientific men in urging legislation, the plan proposed by the National Academy in 1878, and again in 1884, may be carried out with no duplication of other work, but, on the contrary, with cordial and complete co-ordination with other surveys. The whole country would be benefited thereby to an amount far exceeding the outlay.

# EVAPORATION.

By DESMOND FITZGERALD, M. Am. Soc. C. E.

A Paper read before the American Society of Civil Engineers.

The paper gives a description of practical results and a theoretical discussion. It alludes to the many branches of meteorological work, in which experiments must be made to arrive at correct conclusions. The author presents his conclusions as to the natural evaporation from water surfaces. His observations on evaporation at Chestnut Hill Reservoir, Boston, Mass., began in 1876, and were continued until 1882 On examining these experiments, with the idea of compiling a paper, he found that more accurate experiments were necessary, and in 1884 he devised an apparatus to automatically plot a continuous profile of the evaporation on a sheet of paper. A full description of the arrangement of tanks and of the measuring apparatus is given. The experiments were principally made in the Bradlee basin of Chestnut Hill Reservoir, which covers an area of 85 acres, and is about 20 feet deep near the center, where the tank was located. The tank was 10 feet in diameter and 10 feet deep, made of staves of wood, spaced an inch apart, and with a thin copper lining inside. This was in the center of a raft $20 \times 40$ feet, the surface of which was about 10 inches above the water. The raft was anchored in the basin so as to float freely and always present its head, which was arranged to break the waves, to the wind. It was expected that this arrangement would keep the water inside the tank at the same temperature with that in the basin, but it sometimes varied considerably, being somewhat hotter in early summer and cooler in autumn. A maximum difference of 10 degrees was observed. Observations were continued during 1885. The temperatures of the air, of the water in the tank and outside, the dew point, the barometer and the force of the wind were also recorded. On at least one day in each month hourly observations were made.

The three important factors in evaporation are, the temperature of the evaporating surface, the force of vapor in the air, and the velocity of the wind. The maximum evaporation occurs on a cool day, which has been preceded by warm weather; the maximum recorded by the author being 0.64 inch, recorded on June 23d, 1885, when the mean temperature of the air was 10 degrees less than on the preceding day. On December 19th, 1885, with the thermometer at 12 degrees F., an evaporation of nearly $\frac{1}{4}$-inch was noticed. As evaporation during the winter months is so often placed at zero, this is worthy of note. The evaporation from a large water surface is nearly the same, day and night; it may be greater on some days from a considerable body of water than from a shallow pool. The author has observed temperatures of the water at the surface of 82.2 degrees and and 86 degrees. A shallow pool loses this heat much sooner than a large body, following the temperature of the air more closely.

During two months the Lawrence basin of the Chestnut Hill Reservoir was shut off from the city supply for the purpose of making direct measurements of the actual evaporation from a large surface. From September 1st to 22d the evaporation from the reservoir was 3.83 inches, and from the tank in the Bradlee basin, 3.87 inches. The evaporation from the tank was therefore taken as representing very closely that of the reservoir. In the winter of 1878-79 the author made experiments on winter evaporation, the general result being 0.02 inch per day for the winter average. Many comparative experiments between snow and ice evaporation showed that ice will lose twice as much weight as snow in the same time. Evaporation from ice is believed to follow the same laws as that from water. The temperature of the surface of ice does not follow that of the air any more than that of water does.

The actual monthly mean values of evaporation observed were submitted to a mathematical computation by Bessel's Circular Function, and the following table, showing the observed results and

the mean curve of evaporation, was presented:

| Month. | Observed Evaporation. | Mean Curve by Formula. | Per Cent. |
|---|---|---|---|
| | Inches. | Inches. | |
| January.... | 0.90 | 0.98 | 2.51 |
| February.... | 1 20 | 1.01 | 2.58 |
| March..... | 1.80 | 1.45 | 3.71 |
| April..... | 3 10 | 2.39 | 6.11 |
| May..... | 4.61 | 3.82 | 9.76 |
| June..... | 5.86 | 5 34 | 13.65 |
| July .. .... | 6.28 | 6.21 | 15.87 |
| August.... | 5.49 | 5.97 | 15.26 |
| September.. | 4.09 | 4.86 | 12.42 |
| October..... | 2.95 | 3.47 | 8.87 |
| November .. | 1.63 | 2.24 | 5.73 |
| December... | 1.20 | 1.38 | 3.53 |
| Total..... | 39.11 | 39.12 | 100.00 |

Total evaporation for a year, 39.11 inches. The computed curve corresponds very closely with the mean temperature curve.

The author then considers other experiments on evaporation. In this country those by Rev. Samuel Williams, in 1772, the Croton Experiments made by B. S. Church, M.Am. Soc. C.E., and those at Boyd's Corner, by J. J. R. Croes, M. Am. Soc. C.E.; in England, those of Mr. Charles Greaves, C.E., Mr. Miller and Mr. G. Dines; in France, those of Mr. A. Salles, and of the engineers of the Ponts et Chaussées; and in Russia, the extensive experiments of Mr. A. Wild, which are discussed by Mr. Stelling.

Without presenting an extended treatise on the theory of evaporation the author describes the principal facts which it is important to understand. In accordance with the dynamical theory of the constitution of bodies, evaporation is constantly taking place at a rate due to the temperature at the surface, and condensation is likewise going on from the existing vapor in the air passing into the water, the difference between the two processes being what we call the rate of evaporation. The capacity of the air to hold vapor varies with the temperature, so that the same amount of vapor in air will have a very different ratio to the total carrying capacity at two different temperatures. This ratio is called the relative humidity. At any given temperature there is a certain amount of vapor which will saturate the air, and any surplus vapor must be condensed. This vapor has, as a gas, a certain pressure, tension or force dependent entirely upon the temperature, and which may be expressed in inches of mercury. Very accurate tables of the maximum force of vapor for different temperatures have been given by M. V. Regnault. It is upon the amount of vapor in the air that the rapidity of evaporation largely depends. The vapor forming at the surface of water is of the maximum force due to the temperature of that surface. The rate of evaporation depends upon the difference between the maximum force of vapor due to the temperature of the water surface and the force of vapor existing in the air, but it bears no relation to the relative humidity of the air. This is because the temperature of the water surface does not follow that of the air even approximately. The practical determination of the force of vapor in the air is generally made by observing the difference between the wet and dry bulb thermometers, but a more trustworthy method is to take a direct observation by means of some condensing apparatus. The principal points to be considered in the study of the vapor of the atmosphere are: 1st. The temperature of the air; 2d. The dew point; 3d. The force of vapor; 4th. The quantity of vapor in, say, a cubic foot of air; 5th. The additional vapor required to saturate a cubic foot of air; 6th. The relative humidity; 7th. The weight of a cubic foot of air at the pressure at the time of observation.

John Dalton was the first to ascertain the true principles of evaporation. The author having been led by his observations to believe that the rate of evaporation was not in exact proportion to $(V-v)$ as generally accepted, made a series of experiments to determine the exact relation. The formula deduced by the author from his experiments is;

$$E=0.014(V-v)+0.0012(V-v)^3.$$

In which E = evaporation in inches per hour; V = maximum force of vapor at temperature of water; $v$ = force of vapor existing in the air.

A number of experiments were made to ascertain the effect of wind, the result

being a modification of the above formula into the following, viz.;

$$E=[0.014(V-v)+0.0012 (V-v)^2](1+0.67w^{\frac{5}{3}})$$

In which $w$=the force of the wind at the surface of the water.

For an approximate formula, the following convenient forms may be used:

$$E=0.0166(V-v)\left(1+\frac{w}{2}\right) \text{ or}$$

$$E=\frac{(V-v)\left(1+\frac{w}{2}\right)}{60}$$

In the case of his own observations, the author determined by a series of experiments that the velocity of the wind at the surface of the tank was about one-third of that registered by the anemometer, which was located about 30 feet higher.

A series of experiments under the bell of an air-pump was made to determine the effect of barometric pressure, the conclusion being that within the ordinary range of pressure the effect would be hidden by errors of observation; and generally that the influence of the atmosphere on the rate of evaporation is in inverse proportion to its pressure.

In regard to the application of the formula, the author considers that if a sufficient number of accurate observations are made, a very exact result may be reached. The computed result for any given hour is possibly more exact than the observed value.

The author concludes that there is no difference between sun and shade, other things being equal, and that depth has no influence, other than that due to its effect on the temperature of the surface.

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## THE EFFECT OF FROST ON DIFFERENT ROADWAYS.

From "The Engineer."

There is scarcely any condition of weather which has a more injurious effect upon our thoroughfares than frost, especially should it chance to be—as it has been during the winter just passing away—of exceptionally long continuance. Every roadmaker is aware of the risks he runs, under such circumstances, of finding that all his efforts towards perfecting the condition of his roads have been negatived by such an untoward event; and it seems desirable, at a time when so many arguments are being advanced by the advocates of the several systems which are in use among us, to consider which of them is the least liable to be affected by this dreaded enemy. It is as well to use the words "least liable," because all experience goes to show that there is not one of those systems but what is, under certain conditions, open to injurious action upon it by frost. No one could walk the streets of London, for instance, during the late severe weather without noticing that in some way or another one and all of the street pavings, of which this city possesses so many diverse examples, had suffered in some degree from its effects. It will be as well to take the cases categorically, and to make reference first to those macadamized roadways which were the first effort of our progenitors towards improving our means of communication.

Intimately connected with this subject is, of course, that of perfect surface drainage. Frost can have but little effect upon any roadway which, retaining its perfect form, and sound as regards its covering, at once throws off all moisture falling upon it. The basis of its operation is thus lost to the frost, and it must prove altogether inocuous. But this is supposing a condition of things which is impossible of realization. No macadamized roadway can, under the exigencies of traffic, be maintained invariably in the state which alone could insure immunity from the injury under consideration. Inequalities must exist in all such road surfaces, affording a lodgment for water in a greater or less degree, and it matters but little what that degree may be. For it is evident

from the teaching of all experience that the shallower the water film the more quickly is it acted upon and solidified, while the effect in causing injury to the road surface is fully equal to that which may be due to a greater mass of frozen water. In fact, in the case of macadamized roads, it may always be said that the thicker the ice that is formed the less chance there is of the metal being disturbed by traffic while disjointed, so to speak, from the effect of frost. It is therefore often found that roads of this class which are comparatively in a good state of repair, suffer equally, if not even in a greater relative degree, than those which have developed more the results of wear and tear. It is on a form of road construction composed of a mass of units liable to disintegration that frost exercises its most potent effects. The swelling of the innumerable joints inseparable from Macadam's system quickly forces out of position the metal, however thoroughly it may have been consolidated by steam rolling or by a constant stream of traffic. The binding material itself assumes a condition in which it readily pulverizes to mere dust, and as the result we see the roadway under frost covered with loose metal, and each passing vehicle cutting deeper and deeper into the disturbed mass. Such an effect, it would seem, can never be guarded against on macadamized roads. Their construction is of a character which lends itself greatly to aid in the destructive effect of frost. Nor is it alone the center of the roadway—that is, the portion which bears the traffic—that suffers. Injury is particularly liable to occur from the cause named at the edges of the road, unless the side drains where they line the metalling make an almost watertight joint with it. Indeed, it is in such position that frost often exercises its most injurious action. At such points the metalling is, as a rule, greatly reduced in thickness, and although it is less exposed to the disrupting effect of traffic it is more easily permeated by damp from imperfectly cleared side drains, and the thin coat of metal, when that dampness becomes solidified by frost, breaks up almost at once, the *debris* being thrown into the side drains, causing a further blocking of them and intensifying the means of injury. So serious are the results in such instances, that a gentleman well practised in road construction held that it would prove economical to combine the system of asphalting with that of Macadam. He proposed to lay a width of at least a foot along both sides of his roads with metal bedded in asphalt or other waterproof material. But there arose the difficulty that always exists in a combination of systems, that in this case being the impossibility of binding the asphalted line with that of pure macadam work. Weakness at the line of junction would have been sure to show itself as the degree of expansion and contraction under varying sorts of weather differed, and the plan—effective enough, perhaps, had it stood *per se*—had to be given up. No amount of precaution that can be exercised with a due regard to economy can, it appears, suffice to guard against the contingency named, or generally to protect the surface of macadamized roads from the injurious effects of frosty weather.

The conditions under which asphalte is employed as a road covering render it much less liable than is macadam to such effects. An asphalte pavement, when perfect, or even comparatively perfect, may be said to be able to resist almost any amount of frost. Consideration of the effect of it in rendering the foothold insecure must of course be left out of sight in the matter under present discussion. If the pavement be so far in form as to insure a free discharge of moisture into the gullies (there being no side drains to keep clear of water accumulation), asphalte will undoubtedly remain unaffected by weather which would seriously try macadam. But it suffers under one disadvantage to which the latter system is certainly not exposed. It possesses little or no degree of elasticity. When, therefore, there is a force operating to disruption, and assuming this to have obtained a fulcrum for action, there is not with asphalt, as there is with macadam, a function enabling it for a while to resist that force. Supposing this to be sufficiently intensified, the effect is immediate and the injury widespread. The latter must go on extending so long as the frost continues or preventive measures are delayed, and the result is far more ruinous than in the case of metalled roads. Now it is certain that there do occur repeated in-

stances where frost has obtained the fulcrum referred to. Asphalt paving much worn by traffic becomes dangerously thin upon its concrete bed, eventually cracks, and then admits water between it and its foundation. Frost then occurring causes the permeated moisture to swell, and upheaval of the exposed edges follows; further sub-permeation then takes place, and the asphalt comes up in large masses. Nothing, it may be conceived, can guard against such contingency if the pavement is once allowed to become so thin as to be liable to crack under weight. Asphalt is particularly free from any such tendency at a moderate degree of temperature; but under a low range of the thermometer it becomes exceedingly brittle, and therefore particularly liable to such an accident. It has been suggested that the very hardness of the asphalt used in street paving is opposed to its economical employment. Injury to this material is almost unknown during the warm summer months, when it possesses a certain modicum of that elasticity which, as has been said, is wanting to it under the wider range of conditions. The question, as it has been put, is whether it would not be possible by admixture to give it a degree of that quality which, while tending to preserve it during frosty weather, would not adversely affect its traffic-bearing properties. Is it, it is asked, wise to use an entirely unyielding material to carry road traffic? There is an analogy, to a certain extent, between an asphalt roadway and the solid concrete roof coverings used in eastern countries. The more solid and unyielding the character of those coverings, the more certain are they to crack from the contraction and expansion, and consequent movement of the beams which support them. This difficulty appears to have been overcome by those dealing with such roofs by filling in the lines of cleavage where they have showed themselves by a mixture of tar and tallow. Those lines of cleavage once established, rarely diversify themselves, and the elastic character of the filling-in material employed enables them to widen or close up without further injury or without admitting water. It cannot, of course, be said that such a method is applicable to roadways; but it may be admitted that it at least proves the danger of using inelastic material under circumstances which must expose it to disrupting influences. Every roadway is liable to these, and if a mixture could be made which would preserve to asphalt when exposed to low temperature even the small degree of elasticity it possesses at a higher range, it is to be believed that much of the danger now due to the action of frost upon it when used for road surfaces would be done away with. Whether this is possible to be done without militating against the traffic-bearing qualities of hard asphalt, present experience does not prove, but experiments in this direction would not be thrown away.

Wood paving combines in a great degree certain of the peculiarities of both the two systems previously considered. As is macadam, so is wood paving an aggregation of units liable to the same disturbing influences, though in lesser degree, while, like asphalt, it has no perfect unition with its foundation, and is therefore similarly liable to the effect of damp getting below it and being acted upon by frost; but it possesses in an eminent degree the quality of elasticity named as being wholly absent in asphalt paving, while the lesser number of joints as compared with macadam enable them to be treated with a material of a more waterproofing character than is possible with the last-named form of work. But then, on the other hand, the main material employed is essentially porous, and in its untreated condition readily admits of the permeation of damp. Of late years, it may be observed, there has been a tendency to lay such roadways with wood blocks wholly unsubjected to any process of waterproofing. This may be economical in first cost, but it must prove fatal to that quality in the long run. Frequenters of Fleet Street would have probably observed the results to such a method which were apparent in the case of portions of its roadway laid not long since with uncreosoted wood. Under the influence of the frost, the whole roadway in places was upheaved bodily, with what after-results in a financial sense can be easily imagined. In a climate such as ours it must without doubt be one of the primary considerations in laying down any road paving that it should be able to withstand in the fullest

possible manner the effect of our constant rainfall. The practice above referred to is in direct negative of such a manifest precaution. To neglect this is to co-operate with the frost in performing its destructive work; and no idea of saving in first cost should be allowed to induce neglect of guarding against after injury. But there is another point of view which has also lately received strong illustration, from which the effect of frost on wood paving may be considered. The elasticity of this system has before been referred to, but it is, as at present treated, limited to the wood portion of it only. The joints, as now filled in, are eminently inelastic, the asphalt employed being as deficient, of course, in that quality as has been pointed out in relation to paving wholly composed of it. It is certain that wood blocks, especially if uncreosoted, or untreated by some other method of waterproofing, must constantly vary, both in shape and size, during changes of weather. But the movement so caused cannot be followed by the rigid material employed for filling the joints. Hence it must follow that at certain periods there must be found interstices through which damp may percolate from the surface between the blocks and their bed. The arguments advanced in favor of elasticizing—to coin a word—this material have, therefore, additional strength in this relation. Intimately associated with this particular phase of the subject is the question of accurate laying of wood blocks so as to insure perfect uniformity in the width of the joints. If this varies, the causes above named operate with increased strength; the blocks become loosened, shift position, and lose all the quality of bonding with those adjacent, which so greatly adds to the solidity of a pavement. An instance in which the neglect of this common-sense precaution is strongly evident is noticeable in Pall Mall. Cheapness seems to have been the only thought with those responsible for the laying of the wooden roadway in that thoroughfare. The blocks were literally almost *thrown* together, and the result after the late frost should prove a caution for the future against any repetition of such false economy in work of this description. It is not too much to say that the state of the Pall Mall pavement is a disgrace to a city like London. Its center was not many months back, after but a very brief life, taken up and relaid; but the portions of it on either side are really dangerous to traffic, as is almost daily proved by the accidents which occur upon it. That much of its present condition is due to the exceptional opportunity its bad laying offered to the action of recent frosts upon the damp accumulated below it cannot be gainsaid. A wood pavement to resist that action must consist primarily of blocks through which damp cannot penetrate. Secondly, its joints must be accurately laid, and of as little width as may be possible consistently with allowing some expansion of the blocks without producing a disrupting effect; and, thirdly, if it be possible to do so, these joints should be filled with material of a less rigid character than hard asphalte. Elasticity is a condition to the long life of a railroad track, as well as to that of the rolling stock. Equally desirable is it that the same quality should, as far as possible, be secured for ordinary roadways.

There remains but one system of construction to be dealt with—that of paving formed of stone pitchers. As regards the liability of it to injury by frost, it combines the weaknesses of both macadam and wood paving, without the advantages in other respects which are patent in both of those systems. However carefully laid, it can never be said to approach the condition of being perfectly watertight. The grouting it receives, especially as this is commonly applied, certainly never insures that quality, and although the blocks themselves, and consequently the major portion of the road surface, do possess it, the joints may be said always more or less to leak, and the result under frost must follow the rules above quoted. This form of paving is exposed to yet another disability almost peculiar to itself. The grouting under the effects of frost becomes exceedingly friable. With the best workmanship employed and the best material, there must yet always be a certain degree of movement in the blocks under heavy or rapid traffic. When the filling-in material is in the state described this motion acts upon it most destructively, and the defect nullifies the one advantage possessed by stone, that it does not con-

tract or expand appreciably under varying temperatures or climatic conditions. Perhaps to that advantage may be added one other, that of weight, as opposing itself to the swelling action of frost, but it must be manifest that it is only when this last is of a very restricted power that such a qualification can be said to possess any advantage.

To sum up the result of what has been written, it may be concluded that all the various forms of paving roadways as at present practised offer themselves with individual peculiarities to the destructive effects of frost. As immunity from percolation between the material and its bed is the chief safeguard from these, the asphalt paving may certainly be placed first in its qualifications for resisting them, though it has been pointed out that this pavement is not free from a particular danger. The three other systems seem to rank pretty much on a parity; but while the case of macadam seems to be hopeless for improvement, it is certain that in that of wood, at all events, more careful laying and the use of some more elastic material for filling in the joints, would go a long way towards enabling it to resist the action of our severe winter frosts.

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## STANDARDS OF WHITE LIGHT.*

From "Nature."

The experimental work of the Committee during the past year has not been extensive, as they had no funds at their disposal for experimental research, and they have been chiefly occupied with reviewing what has been done in the past and laying plans for future operations.

Lord Rayleigh has constructed an instrument which he calls a monochromatic telescope, by means of which the illuminated screens of a photometer may be examined, allowing light only of one definite color to pass. It was hoped by Lord Rayleigh that experiment might show that, with some suitably chosen color, this instrument, used with any ordinary photometer, would, in comparing lights of different intensities and temperatures, give to each a candle power which would be sufficiently accurate to represent for commercial purposes the intensity of the light. The Secretary has made some experiments at the Society of Arts, where he was kindly permitted to use the secondary batteries and glow-lamps; but the results so far are not definite enough to justify their publication.

Mr. Vernon Harcourt has been engaged on an investigation on the barometrical correction to his pentane standard, and on another concerning the possibility of using lamp-shades as a protection from air-currents. His researches are communicated independently to the meeting.

Capt. Abney and Col. Festing have continued their observations on the intensity of radiations of different wavelengths from incandescent carbon and platinum filaments at different temperatures, which will go far to assist the committee in their work.

Other isolated experiments have been made by members of the committee, which will be published in due course.

Most of the members have examined the experiments of the Trinity Board at the South Foreland.

*Existing Standards.*—A consideration of existing standards convinces the committee that the standard candle, as defined by act of Parliament, is not in any sense of the word a standard. The French "bec Carcel" is also liable to variations; and with regard to the molten platinum standard of Violle, it seems that the difficulty of applying it is so great as to render its general adoption almost impossible.

With regard to the so-called standard

* Report of the Committee, consisting of Prof. G. Forbes, Capt. Abney, Dr. J. Hopkinson, Prof. W. G. Adams, Prof. G. C. Foster, Lord Rayleigh, Mr. Preece, Prof. Schuster, Prof. Dewar, Mr. A. Vernon Harcourt, and Prof. Ayrton, appointed for the purpose of reporting on Standards of White Light. Drawn up by Prof. G. Forbes (Secretary).

candle, the spermaceti employed is not a definite chemical substance, and is mixed with other materials, and the constitution of the wick is not sufficiently well defined. Hence it is notorious that interested parties may prepare candles conforming to the definitions of the act which shall favor either the producer or consumer to a serious extent. In view of these defects of the standard candle, it is a matter of great importance that a standard of light should be chosen which is more certain in its indications.

The Committee have looked into the merits of different proposed standards, and the majority feel satisfied that, for all the present commercial requirements, the pentane standard of Mr. Vernon Harcourt—since it has no wick and consumes a material of definite chemical composition—when properly defined, is an accurate and convenient standard, and gives, more accurately than the so-called standard candle, an illumination equal to that which was intended when the act was framed.

Yet the committee, while desiring to impress the Board of Trade and the public with these views, do not feel inclined at present to recommend the adoption of any standard for universal adoption until, further information on radiation having been obtained from experiment, they may learn whether or not it may be possible to propose an absolute standard, founded, like electrical and other standards, on fundamental units of measurement—a standard which, for these reasons, would be acceptable to all civilized nations. They are, however, inclined to look upon the pentane lamp as an accurate means of obtaining an illumination to replace the so-called standard candle.

*Proposed Experimental Researches.*—Radiation is measured as a rate of doing work, and consequently radiation might be measured in watts. The illumination (or luminous effect of radiation) depends partly upon the eye, and is a certain function of the total radiation. This function depends upon the wave-length of the radiation, or on the different wave-lengths of which the radiation, if it be compound, is composed. This function of the radiation perceived by the eye is partly subjective, and varies with radiations of different wave-lengths and with different eyes. Thus the illumination cannot, like the radiation, be expressed directly in absolute measurement. But the connection between the illumination and the radiation can be determined from a large number of experiments with a large number of eyes, so as to get the value of the function for the normal human eye. This function, however, is constant only for one source of light, or, it may be, for sources of light of the same temperature. It appears, then, that, in the first instance at least, a standard should be defined as being made of a definite material at a special temperature.

The energy required to produce a certain radiation in the case of a thin filament of carbon or platinum-iridium heated by the passage of an electric current can be easily measured by the ordinary electric methods, and the radiation may be measured by a thermopile or a bolometer, which itself can be standardized by measuring the radiation from a definite surface at 100° C., compared with the same at 0° C. The electric method measures the absorption of energy; the thermopile measures the total radiation. These two are identical if no energy is wasted in convection within the glass bulb of the lamp, by reflection and absorption of the glass, and by conduction from the terminals of the filament. Capt. Abney and Col. Festing have come to the conclusion that there is no sensible loss from these causes. The committee propose to investigate this further. This constitutes a first research.

No research is necessary to prove that with a constant temperature of a given filament the luminosity is proportional to the radiation, because each of these depends only upon the amount of surface of the radiating filament. It will be necessary, however, to examine whether with different filaments it be possible to maintain them at such temperatures as shall make the illumination of each proportional to the radiation. This will be the case if spectrum curves, giving the intensity of radiation in terms of the wave-length when made out for the different sources of light, are of the same form. Thus a second research must be undertaken to discover whether the infinite number of spectrum radiation curves, which can be obtained from a carbon filament by varying the current, are iden-

tical in form when the filament is changed, but the material remains so far as possible of constant composition.

It will be an object for a later research to determine whether, when the radiation spectrum curve of any source of light has been mapped, a similar curve can be found among the infinite number of curves which can be obtained from a single filament.

The next step proposed is to examine a large number of carbon or of platinum-iridium filaments, and to find whether the radiation spectrum curve of different specimens of the same material is identical when the resistance is changed in all to $x$ times the resistance at 0° C. If this law be true, a measurement of the resistance of the filament would be a convenient statement of the nature of the radiation curve. If, then, a number of filaments were thus tested to give the same radiation spectrum curve, their luminosities would in all cases be proportional to their radiations, or (if there be no loss in convection, conduction, absorption and reflection) proportional to the electrical energies consumed.

Thus it might be hoped to establish a standard of white light, and to define it somewhat in the following manner: *A unit of light is obtained from a straight carbon filament, in the direction at right angles to the middle of the filament, when the resistance of the filament is one-half of its resistance at 0° C., and when it consumes* $10^{0}$ *C. G. S. units of electrical energy per second.*

Since Mr. Swan has taught us how to make carbon filaments of constant section by passing the material of which they are composed through a die, it is conceivable that another absolute standard should be possible—viz., a carbon filament of circular section, with a surface, say, 1-100th sq. cm., and consuming, say, $10^{0}$ C. G. S. units of energy per second.

Whether such standards are possible or not depends upon the experiments of the committee. The probability of success is sufficient to render these experiments desirable.

*Proposed Later Experimental Researches.*—Should these hopes be realized, and an absolute standard of white light thus obtained of a character which would commend it to the civilized world, it would then become an object of the committee to find the ratio of luminosity when the radiation spectrum curve of the standard filament is varied by varying the current, and consequently the resistance of the filament.

Thus, by a large number of subjective experiments on human eyes, a multiplier would be found to express the illumination from the standard lamp, with each degree of resistance of the filament.

A research, previously hinted at, would then be undertaken—viz., to find whether the radiation spectrum curves of all sources of illumination agree with one or other of the curves of the standard filament. It is not improbable that this should be the case except for the high temperature of the electric arc.

Should this be found to be true, then photometry would be very accurate, and the process would be as follows: *Adjust the standard filament until its radiation spectrum curve is similar to that of the light to be compared.* (This would probably be best done by observing the wavelength of the maximum radiation, or by observing equal altitudes on either side of the maximum, the instruments used being a spectroscope and a line thermopile or a bolometer.) The total radiation of each is then measured at equal distances by the thermopile. The resistance of the filament is measured, and its intensity in terms of the unit of white light obtained therefrom by the previous research. The luminosity of the compared source of light is then obtained directly.

The committee desired to be reappointed, and to enable them to carry out the researches indicated they ask for a grant of £30.

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EXPERIMENTS of Herr J. Koeing on self-purification of rivers, act on the fact that water possesses the power of rapidly absorbing oxygen when presented to it in the state of spray or a thin layer. The author had an apparatus constructed of finely perforated metal, over which he caused a stream of water to flow, most of it descending in fine rain and being largely in contact with the air. Ordinary potable as well as sewage waters were experimented with, and the results were very satisfactory, the oxygen absorbed being considerable in amount. It is recommended that when sewage water is discharged into rivers such should be chosen as have a long course and a rapid flow, presenting considerable surface to the atmosphere.

# THE MECHANICAL ART OF AMERICAN WATCHMAKING.

By Dr. LEONARD WALDO.

From the "Journal of the Society of Arts."

The study of the evolution of a mechanical art in any country is a study in social and political as well as in mechanical science. It often depends for its rapid and progressive growth on the characteristics of the people among whom it is planted. Of no art is this principle more true than of the art of machine watch and clockmaking in the United States. Born among a people who from the beginning of their history had to construct their own devices and machines of all kinds, it has had the same growth and individuality which characterizes the manufacture of locomotives, agricultural implements, or house fittings and decorations. Unlike these classes of manufacture, however, and more analagous to the production of firearms, the clock and watch products are suited to other people and other countries. It is the economic question growing out of these facts which has led to my appearance before you this evening, in the somewhat unique position of a visitor from the United States, explaining to an English audience the conditions of growth in a great industry, in the early development of which England for many years maintained the leading position.

One of the sayings which we hear more frequently in England than in the United States, is that the preliminary training for a great President is to be found in rail-splitting or on the towpath of a canal. The truth underlying this homely remark is, that in the United States the freedom from supervision, the assumption of tasks, the absence of help, the necessity for doing things as quickly as possible, the great variety of work which comes to the American boy early, gives him practice in solving new problems without considering precedents. He is obliged to face new difficulties constantly, and he has no one to appeal to for help.

Throughout the country I think you will often be struck with the general mechanical intelligence of artisans. The plumber is pretty apt to know something of carpentry and metal work; the metal worker can paint, or turn from iron to brass. The lines of caste in the mechanical arts are so loosely drawn, that the artisan of one trade is often found, in dull time, at a "job" in quite another department of labor. This versatility is a characteristic of the native American; it is less true of the Irish or the German emigrant who settles amongst us. The presence of this pure American type, the abundant use of water-power, the impossibility of competition in agriculture with the other sections of the United States, early led to the seclusion of New England as the manufacturing district. The phrase "as inventive as a Connecticut Yankee," came from the fact that in Connecticut and the rest of New England the artisan class grew rapidly in numbers, and protected by wise legislation in regard to the patenting of inventions, every artisan feels there is a possible road to wealth in perfecting the tools he is working with, or the method of production of the thing he is working at. At any rate, patents are cheap and quickly obtained; he will take the risk, he thinks, and work in his own line to better his condition. He constantly sees his fellows transferred from the ranks of workmen to that of employer and manufacturer, and the result is that he cares little for trade practices, for custom, for what is old; he is only anxious to improve the present modes, to attain his own success.

It was a mind of this type which showed itself in the son of a shoemaker (who was also colonel in the State Militia) in the little town of Brunswick, Maine. Born in 1812, Mr. Aaron L. Dennison had the training which might be characterized as Presidential, for he carried a mason's hod at the age of ten, and changed his occupation to that of caring for a herd of cows at eleven. At thirteen he found himself sawing wood and

strengthening his constitution for the cares of later life, and a year or so later he was promoted to that position from which so many bright ideas in life have come, the shoemaker's bench. At eighteen his dissatisfaction with this bench led him to take to another, and we find him apprenticed to a clock and watchmaking firm in his native town, where he stayed till he was of age. He left the town of his birth in 1833 to perfect himself as a journeyman watch and clockmaker, going to Boston, where were then good facilities for learning the higher branches of the horological art. His thoughts soon turned upon the organization of labor in the production of watches looked at as machines for time-keeping, and independent of a value as articles of jewelry or art. It is to be borne in mind that from the beginning of the horological art it had been associated with the workers in the precious metals. The promptness of the driving business life throughout the civilized world was but beginning to be felt in its modern force. Few people cared for the minutes of time in domestic timepieces, still fewer for the seconds. The modern ideas were undeveloped, of synchronized clocks, of observatory time-signals, of swift trains, of banking hours, and stock exchanges in which seconds were of high financial value, of thousands of miles of telegraph wire in the same clock electric circuits once or twice every day, so that Greenwich or Washington time might be furnished with unerring exactitude to railroad superintendent or guard alike. The great public yet were unfamiliar with modern business competition and consequent necessity for extreme uniformity of time in engagement, which is an unconscious accompaniment of the life of to-day. But it was all dawning, and to the mind of Dennison it seemed that timepieces should be made simple in pattern, alike in parts, so that pocket watches could be made in enormous numbers, on principles analogous to those in the manufacture of firearms. The idea haunted him.

He writes:

"The principal thinking up of the matter was done when I was in business at the corner of Bromfield and Washington streets, Boston; and many a night, after I had done a good day's work at the store and a good evening's work at home in repairing watches for personal friends, I used to stroll out upon the common and give my mind full play upon this project. And now as far as I can recollect what my plans then were as to system and methods to be employed, they were identical with those in existence at the principal watch factories at the present time."

In 1840, Mr. Dennison predicted "that within twenty years the manufacture of watches would be reduced to a system as perfect and expeditious as the manufacture of firearms at the Springfield armory." Capital was not forthcoming, however, to what seemed a visionary scheme. It was not until 1849, when a friend, Mr. Edward Howard, approached him for his advice as to the expediency of setting up works for the manufacture of American locomotives, that he had the opportunity of suggesting the probable paying qualities of an establishment for making watches as other machinery was made with interchangeable parts, in large quantities, and with the principles of shop management of mechanicians rather than of the watchmakers. This proposal impressed Mr. Howard more favorably than his own plan for building locomotives. Together they found a capitalist willing to share with them the risks of the adventure. I shall use Mr. Dennison's own words as to what followed the meeting of the three projectors:

"I suggested that the first money spent in the undertaking should be for a tour of observation in the watchmaking districts in England, with the view of ascertaining whether the trade of watchmaking was carried on there on the system represented to me by English workmen I had employed from time to time in repairing. Another object I had in view was to find out the source of supply for the necessary materials, such as enamel for dials, jewels, &c."

Then he goes to England on the proposed mission, and writes in regard to it:

"I found that the matter had been correctly represented, but in carrying out their system one-half the truth had not been told. How that the party setting up as manufacturer of watches bought his Lancashire movements—a conglomeration of rough materials—and gave

them out to A, B, C and D, to have them finished; and how A, B, C and D gave out the different jobs of pivoting certain wheels of the train to E, certain other parts to F, and the fusee cutting to G. Dial making, jeweling, gilding, motioning, &c., to others, down almost the entire length of the alphabet; and how that taking these various pieces of work to outside work people—who, if sober enough to be at their places, were likely to be engaged on someone's work, who had been ahead of them, and how, under such circumstances, he would take the occasion to drop into a 'pub' to drink and gossip, and, perhaps, unfit himself for work the remainder of the day.

"Finding things in this condition, as a matter of course, my theory of Americans not finding any difficulty in competing with the English, especially if the interchangable system and manufacturing in large quantities was adopted, may be accepted as reasonable."

I cannot omit, in this connection, a reference to the contemporary art of the application of machinery to watchmaking in France as well as to England. By reference to documents, now in the Guildhall Library, of the Clockmakers' Company in London, I find that the Clockmakers' Company opposed the erection of works and the granting of a charter to a company, known as the "British Watch and Clockmaking Company. (By Royal Letters Patent.) Capital, £250,000 in 10,000 shares. Deposit, £2 10s. per share." In a report of a committee of the guild, they review the attempts of Mr. Ingold to establish companies for systematizing the production of watches and clocks in Paris in 1835, concerning which the committee says:

"The committee is enabled to state it failed entirely, without realizing anything to the parties who embarked their money on the speculation. It was scarcely two years in existence, for early in 1838, Mr. Ingold was in London, endeavoring to open a door to transfer his unsuccessful project to the shoulders of the British public, but the bait at that time was not alluring, and the project for a season abandoned.

"The Parisian Watchmaking Company having expired, a similar company, with similar pretentions, without the name of Mr. Ingold attached to it, made its appearance at Versailles in the year 1838. By some it is denied that Mr. Ingold belonged to this establishment, but it will require more than simple assertion to make such statement credible. The prospectus of this company, issued in 1838, contains the following: Manufacture of French watches, established at Versailles, under the special protection of the king. The manufactory which, from its commencement, has obtained the powerful patronage of the king, has been in full operation since 21st February, 1838. It already employs more than 200 workmen, attracted from the best workshops of France and foreign countries. It is not a matter of speculation—it is a thing accomplished. A board of manufacturers, including the principal watchmakers of Paris, MM. Lepante, Lessine, Charles Leroy, Robin Mathieu, constantly overlooks the perfection of the works.

"The object of the company is to liberate France from the tribute she pays to a foreign country, and to restore to our commerce a part of the thirty millions at least which are drained yearly to buy more than 120,000 watches from Geneva. The company is already in a position to satisfy all orders for watches from 200 to 600 francs; it can multiply the number of its productions by means of the perfect machines which it possesses. By the aid of those machines the principal parts of a watch are made of uniform size and great quickness; the precise exactness is an invaluable advantage, which alone renders the establishment without a rival of its kind.

"A watchmaker who visited this vaunted establishment in 1839, has given the committee the following particulars: I was introduced into spacious premises; two or three directors received me with much courtesy. I was shown a large room containing machinery for escapement making, &c., but of the two hundred men said to be employed, the number I saw did not exceed six or eight, these were occupied in making watches without the aid of machinery, employing only the tools generally in use. I did not see a single complete watch. The person who introduced me to this establishment called at my house in London in 1840, and told me that it was defunct. It is remarkable that coincident with the periods at which the formidable machin-

ery of these companies ceased to move, Mr. Ingold came to reside in London and renewed his canvass for support to a 'British Watch and Clock Making Company' which, increasing its pretensions, has put forth its title to the trade of the whole world.

"The committee has in vain attempted to discover the names of those 'most experienced makers of watches in London, those men prominent in science, not one of whom has expressed a doubt of the efficacy of the machinery to facilitate the manufacture of watches, or of the fact that work so produced will be incomparably superior to that done in the usual way.' On the contrary, some of our manufacturers and several of our practical and scientific workmen who have seen the machinery, have not only directly denied the possibility of its success, but have rejected advantageous overtures to identify themselves with the company.

"In reference to the objects of the company, and the powers it assumes to possess, the committee, as practical men, nurtured in the watchmaking business, explicitly states its conviction and belief that they are absurdly and fallaciously stated. It has given the company an opportunity to prove before it the powers and applicability of its machines to effect the miracles that have been ascribed to them. At an interview, 22d March, 1843, on its premises at 75 Dean street, Soho, they were then requested, urged, and challenged to exhibit proof of the working of their machinery before your committee. The favor was claimed on behalf of the trade at large. This request was refused upon the most frivolous and contradictory pretexts. The committee advisedly declares its firm persuasion that the company is not in a capacity to make good its assertion upon the subject of letters patent which have been taken out to secure these newly invented machines to the company, the committee would remark that the specifications have not yet been enrolled. It considers the features of the case to present the strongest ground for a petition to Parliament, praying it to refuse its sanction to the doubly concentrated monopoly. The rise and progress of this adventure has been thus far traced, together with the career of its founder; he has failed in carrying out a similar object in Switzerland, in Paris, and in Versailles, and he is now reasserting the same pretentions, the stale romance of twenty years, upon the credulity of the British public.

"It may be asked, if this undertaking be founded on such a visionary basis, why not leave it unnoticed to fall piecemeal into ruin?

"The reply is evident and conclusive. At the same time that its failure is most confidently predicted, the consequences devolved in its destruction are not to be lightly regarded. At a time when the watch trade is languishing in sympathy with every branch of our national industry, the uncontradicted assertions of the company's prospectus have aggravated the depression; and although manufacturers of watches are fearless of competition, and regard as impracticable the success of the company, yet they cannot conceal from themselves the fact that a large capital worked against them, under the protection of monopoly legalized by Act of Parliament, though for a limited period, may severely prejudice their interests, and involve a large body of industrious workmen in privation and distress."

The bill for the formation of the English company was thrown out by the House of Commons, on the 31st of March, 1843.

It has been stated in English horological circles that Mr. Dennison had the benefit of Mr. Ingold's ideas and inventions in the formation of his own company in the United States. I cannot find any evidence that this is a fact; and in this connection, as a contribution to the history of the early American horology, I will give Mr. Dennison's own statement of his knowledge of Mr. Ingold and his schemes.

"I have to say I never heard of Mr. Ingold or his operations until after our factory was built at Roxbury, and were hiring our workpeople. An applicant for a situation, a Frenchman by the name of Boudet, I hired to do the facing of pinions, as that work required some hand manipulation such as no machine which had been thought of at that time could do it so well—so far as I know, the thing has not yet been accomplished. This man Boudet told me that he was a son-in-law of Mr. Ingold, and, I think it fair

to conclude, had worked for him in London; but I have no recollection whether he told me so, or whether he informed me of the connection between himself and Mr. Ingold at the time, or after he had been at work some time. I never saw Mr. Ingold, but I knew of his being about in Switzerland during our residence there. I never knew of his being in America until a long time after we came here (Roxbury) to live. I always had the impression that the British Watch Company obtained an act, as I was told by Boudet, or some one I thought knew, that it cost, to obtain the act, £30,000; and that the machine which he got up for making the plates alone cost £6,000."

The first company formed in the United States was not, financially speaking, a success, neither was the second. There had not then been found the financial ability for the head of such a company, and it was not found until May of 1867, when Mr. Royal E. Robbins bought the factory for $56,000—on which Mr. Dennison, his friends and successors, had expended some $250,000—at an auction sale.

It was one of those happy assumptions by a man who had great capacity and a recognized financial ability, of a great manufacturing interest, to which he proposed to bring the new and needed element of business sagacity. It became the precedent for the formation of other companies, and now, instead of the single company at Waltham, there are in the United States its great and well-managed rival company at Elgin, Illinois, and the smaller companies at Rockford, Aurora, Springfield, Ill., and Springfield, Mass., Nashua, N. Y., Columbus, O., Fredonia, N. Y., and Thomaston, Conn., and I am told there are nine others at the present writing in process of organization. The combined output of these factories, which produce watches of durability and a certain excellence of manufacture, is not far from 4,000 per day, of which the parent company produces about 1,100, with a machine capacity for 500 more per day.

The total population interested in the manufacture and selling of watches and clocks, directly and indirectly, in the United States, is not far from 100,000 people, and the sales of the leading company during the year 1884 amounted to $3,900,000 of products.

To give some idea of the extent of the entire industry in 1880, I quote the following table, made up from the returns of the United States Census for that year, remarking that the industry has very much increased since that date:

TABLE SHOWING THE STATISTICS OF CLOCK AND WATCHMAKING IN THE UNITED STATES IN 1850.

| Subjects. | No. of establishments. | Capital. | Average No. of hands employed. | | | Total paid in wages per year. | Value of materials. | Value of products. |
|---|---|---|---|---|---|---|---|---|
| | | | Males over 16 years. | Females over 16 years. | Children or youths. | | | |
| Clocks..... | 22 | $2,474,800 | 2,807 | 630 | 503 | $1,622,693 | $1,908,411 | $4,110,267 |
| Watches..... | 11 | 4,144,327 | 2,127 | 1,219 | — | 1,712,276 | 982,224 | 3,271,244 |
| Watch Cases..... | 27 | 1,584,740 | 1,418 | 139 | 201 | 976,041 | 2,812,922 | 4,589,314 |
| Watch and Clock Materials..... | 20 | 117,550 | 184 | 45 | 49 | 86,050 | 130,315 | 300,195 |
| Totals..... | 80 | $8,321,517 | 6,536 | 2,033 | 753 | $4,397,060 | 5,833,872 | 12,271,020 |

It is not to my purpose to follow out the actual making of individual watches by machinery; that is quite impossible in an hour's paper. The study of a machine for the automatic manufacture of screws alone could occupy the time. The

object is rather to analyze the broad difference in the requirements of the industry when it is transferred from the journeyman's bench to the well-appointed machine shop. I shall draw my illustrations from the great company to which I have already referred, having its location at Waltham, a little town some twenty miles from Boston, in Massachusetts. I do this because this company exhibited a very fine array of its machines at the Inventions Exhibition, and my effort now will be to add to your knowledge there gained, the ideas of policy and management regulating such a great establishment.

A new people is not an art people. It takes age, leisure, and accumulated wealth to give masses of the people artistic ideas. The first test they apply to any new machine is that of utility. In the United States this is a fundamental element of the early success of the watch companies. Automatic machines are very costly. No one can afford to make automatic machines for a thousand watches, or for a hundred thousand. It is only when a simple type can be made and have an enormous sale, that machinery can be extensively applied. In the United States the company of which I speak barely lived until the Civil War broke out. Immediately there was a great demand for watches, strong, serviceable, uniform in quality; there was an opportunity to make a simple type. The buyers were not critical as to finish, if only the watches would run. They did not require art in the case, so long as it was strong. A minute a day was accurate enough for their use, and the art could easily enough produce such timepieces. There was the opportunity. The factory which paid no dividend at the beginning of the war, paid 4 per cent. the first year, 11 per cent. the second, 22 per cent. the third, and two dividends of 60 and 150 per cent. the last year of the war. It would have been impossible to pay any such dividends except that the watches were of simple types—interchangeable parts—screws, plates—hands, wheels, and dials, all manufactured by machinists, running well-made machines, under the supervision of machinist foremen.

The machinery was built and paid for. The great questions of getting homogeneous raw material, of learning the capacity of machines, of determining what kind of labor—whether of boys or girls, or men or women—was most efficient in any given department, had been settled. Through the simple, cheap, but efficient work of the years from 1857 to 1865, the whole art of machinery, as applied to making watches, was being studied by men of the highest mechanical and business ability, and without the slightest regard to any preconceived trade notions or customs or traditions. The great idea was that millions of now civilized people wanted watches, with China, and Japan, and India and Africa yet to be heard from.

To create and to supply any such possible demand would require the same business organization as the supply of cottons or metal ware. There must be an organization reaching from the selection of the raw material to the selling of the product in distant markets. To secure homogeneity of material, *i.e.*, uniform texture of the metals employed, without which machine-made watches would be of temporary value, the most recent advances in physics and chemistry must be made use of. To time the watches properly, not only are the observatory time signals from Harvard University used, but a separate observatory, fitted up with a recording chronograph and transit instrument of a refined construction, has been erected. A dark room, with all the apparatus for experimenting in photographic processes of reproducing dials, &c., is in full operation. Systematic experimenting in tempering steel, in testing metals for their physical properties, is carried on, and some of the most exquisite physical apparatus I have ever seen, I have seen in these measuring-rooms. Those of you who are microscopists, and who know of the extreme accuracy of the small standards of length, made by Professor W. A. Rogers, of Harvard University, need only be told that the most beautiful of his smaller machines was built and used at the Waltham Watch Factory, under the combined direction of himself and the mechanical superintendent.

Given a scientific knowledge of the raw materials, a certainty in their selection, and it becomes possible to reproduce the hand processes of manufactur-

ing the small parts of watches by automatic machines. This requires the fundamental department of the company — a well appointed machine shop, in which their machinery can be constructed and repaired. This machine shop occupies the three stories of a wing 150 feet long. The operatives from this department have the constant supervision of the machines, which are systematically arranged along the three and a-half miles of work benches which extend over the nearly five acres of floor space covered by the main buildings. For driving the machinery throughout the factory, a Corliss engine of 125 horse-power works through 39,000 feet of belting, 10,600 feet of main shafting, 8,000 feet of wall rods, and 4,700 pulleys. The number of operations, most of them accomplished by automatic machinery, which is "tended" by a young woman or man having no special knowl- of horology as a whole, in the manufacture of, say, the common "18-size full plate, keyless, four-pair jewels" watch movement is, by count of the twenty-five foremen of the different departments in which it is made up, about 3,746.

The American system of manufacturing by interchangeable parts means much more than making a part under the roof of a factory, buying other parts in the market, and obtaining other parts by the piece from workpeople who live in their own cottages, for which they are paid at piecework rates. It means the establishment of working facilities for the entire manufacture. That everything is made on the premises, not according to the plans or ideas or methods of work of individual workmen, but under the direct supervision of a company's foreman, according to gauges the company furnish, under conditions of time, cleanliness and care which the company prescribe. The operative himself is a machine. There is as little as possible variation in the drill of a great factory.

The results of this are shown in a promptness of delivery, in a uniformity of products, utterly unattainable under the prevalent methods of what is called the factory system outside of the United States where the work of operatives is collected from their local habitations to be made up into timepieces at a central putting together establishment.

A little later in the evening we shall see, from the photographs, the various departments of a great watch factory, and I pass now to other considerations of interest to you. It is already apparent to you that the master-mind of such a company is to be chosen for his general executive qualities, and his ability to conduct a manufacturing business, rather than his technical knowledge of watches. In 1884 there were 2,500 operatives in the factory we have quoted. Only a few, and those in the designing and putting together departments, were professional horologists. There are machinists, and draughtsmen, and die sinkers, and steel workers and gilders, and enamelers and photographers, and men of many trades, each working in their own departments. Their tools are found by the company, they work on the company's premises, they report at a given hour, have certain intervals for rest, and go home at another hour. They are exposed to the strictest supervision during the progress of their work, and they have every attention given to their personal comfort. Plenty of light, plenty of fresh air, and a comfortable warmth pervades every part of the enormous buildings, to which the 2,500 (in 1884) operatives repair every morning for their duties. Taken all in all, I believe it is the most intelligent body of operatives in any industry known to me. Making up, as they do, the community in a very cultivated part of New England, they have every opportunity in the way of libraries, literary clubs, church life, and social advantages. One is very much impressed with the intelligence, taste, and general attractiveness of the operatives generally, and the women in particular, as they sit at their benches and machines. The delicacy of their work and the *esprit de corps* of the entire body are the two conducing factors to this result. In giving employment, a good character is insisted on. It is rather a remarkable fact that almost the entire number are native born American, with very few, almost none, of the Irish, who are most numerous in other systems of manufacturing. The morality of the young women is on a par with their general intelligence. It is very rarely indeed, that one is found against whom the breath of scandal is heard. Marriage amongst the operators is frequent, and the romance of life is not ignored.

Homes are made as well as watches. There has grown up in the factory the spirit of interest in its social associations, in its products, and an interest in its reputation, which can only come of a large, industrious, intelligent, well-fed and well-paid community. The company finds it to their interest to maintain these feelings among the operatives. Parks are laid out; cottages, which are both tasteful and healthful, are built; good drainage and ventilation are secured; trees, flowers, lawns are used to beautify the homes, streets, and grounds about the factory buildings. A large hotel has been built for the exclusive use of the young women who are not married, and who wish to live in it. I had the pleasure of dining at this hotel, in the dining-room at the tables of which about 120 young women were seated. The meal was nicely served and consisted of roast beef, roast mutton, potatoes, corn (maize), turnips, with apple pie and coffee and cheese for dessert. The charge which the company makes for board alone is $2.25 per week, or for board and lodging, $3 per week. Breakfast is served at half-past six in the morning. Now, when we consider the average pay of the women on the rolls is $7.98 per week, it can be understood that they have a margin for dress and other things which makes their life quite attractive to them. With their general intelligence there is borne the natural desire to become skillful and expeditious in their work. They become specialists with the new machines put into their hands. They know machinery to be their friend, for anything which will make two watches where one was made before, will halve the cost of the watch, but will not halve their wages, and will make their services still more valuable to the company. They are not afflicted with trade notions or customs; they are thoroughly malleable in their methods of work, and quick to do any new thing required of them. They are inventive and suggestive.

Under the administration of such great establishments there have grown up completely new methods of work. The claim that the machinery, processes, methods of organization of a great American watch or clock company are not original, is as ridiculous as to say that the Falls of Niagara are not original. The one is as much a product of the inventive genius, the disregard of trade laws and customs, the intelligence and necessity of production of an Anglo-Saxon country, separated by 3,000 miles of water from any other Anglo-Saxon country, as the Falls of Niagara are the product of the waters of the lake basin, and the topography of its outlet. The machines of these places are unique. They must be so, they are made on the premises to suit the individual needs of the establishment. For some of the important processes there are as many kinds of machines as there are distinct factories in the United States.

So far we have been referring to the middle class of watches, made in lots of many thousand at a time, and designed for general use. But it is evident that it needs only the addition of the adjuster's skill to produce on the same system, timepieces of a very high precision of running. So the leading American watch companies have put forward the claim that it is only necessary for them to add an adjusting department to their factory organization, and they will produce timepieces which will be much less in price, and equal in performance to the timepieces made by the very best foreign producers on the old systems. So such adjusting departments have been added to several of the leading factories. In these departments a watch is rated and adjusted to position and temperature for periods ranging from a week to six months, depending on the price at which the movement is to be sold. The watches which are meant for the very finest timekeeping are adjusted at two extreme temperatures, and in the fine positions of dial up, dial down, pendant up, pendant right, and pendant left. The adjustment of a watch is somewhat analogous to the adjustment of sights on a rifle. All the parts of an admirable weapon may be there, and the sights may be approximately right; but it takes actual trial and the slight adjustment of the sights to make any given rifle do its most accurate work.

As far as the success attained by the American method in watches of the very highest class is concerned, I can do no better than to quote the results of the trials of timepieces at the observatory in Yale College, made under the direction of the Corporation of the College for the

years 1881 and 1884 inclusive. Their trials are conducted at the Observatory of Yale College, and involve the daily comparison of watches in the following positions and temperatures, for a total period varying from six weeks for watches of the highest class, down to twelve days for watches of simpler adjustment, according to the following schedule:

| Test No. | Position. | Approximate Temperature. | Number of days trial for Class Certificates. | | | |
|---|---|---|---|---|---|---|
| | | | I. | II. | III. | IV. |
| 1 | Dial vertical, pendant up | 60° to 70° F. | 7 | 8 | 8 | 12 |
| 2 | Dial vertical, pendant right | 60° to 70° F. | 2 | 2 | — | — |
| 3 | Dial vertical, pendant left | 60° to 70° F. | 2 | 2 | — | — |
| 4 | Dial horizontal, dial down | 60° to 70° F. | 2 | — | — | — |
| 5 | Dial horizontal, dial up | 60° to 70° F. | 10 | 8 | 8 | or 12 |
| 6 | Dial horizontal, dial up | 34° to 38° | 1 | 1 | 1 | — |
| 7 | Dial horizontal, dial up | 95° to 100° | 1 | 1 | 1 | — |
| 8 | Dial horizontal, dial up | 60° to 70° | 10 | — | — | — |
| 9 | Dial vertical, pendant up | 60° to 70° | 7 | — | — | — |
| | Total number of days | ——— | 42 | 22 | 18 | 12 |

The conditions excluding watches from receiving certificates of any class were as follows:

1. When the variation of rate with the dial vertical and pendant up in classes I., II., III, and in the positions indicated in class IV., exceeds $2^s.0$ from one day to the following day.

2. When the variation of rate between the positions of "dial up" and "dial vertical" exceeds $10^s.0$

3. When the variation for 1° F. exceeds $0^s.3$ between the ordinary temperature and the oven.

4. When the rate is greater than $10^s.0$ per day in any position.

The number of watches entered for the period under consideration was as follows:

| | |
|---|---|
| 1880–81 | 219 |
| 1881–82 | 53 |
| 1882–83 | 41 |
| 1883–84 | 87 |

and the analysis of the results of watches of the highest class for the four years, is as follows:

| | 1880–81. | 1881–82. | 1882–83. | 1883–84. |
|---|---|---|---|---|
| Per-centage of watch movements receiving certificates of any kind, excluding watches entered for rate records | 45 | 38 | 28 | 77 |
| Number receiving Class I. certificates | 22 | 12 | 8 | 42 |
| Average mark of Class I. certificates | 68 | 68.6 | 76.4 | 74.4 |
| Average mark of the first five watches receiving Class I. certificates | 79.4 | 77.0 | 80.4 | 85.8 |
| Highest mark received during the year | 83 | 82 | 85 | 90 4 |
| Makers' name of watches receiving the mark during the year | American Watch Co. Waltham. | Barraud & Lunds, London. | Vacheron & Constantin, Geneva | American Watch Co., Waltham. |

In reference to these "marks" I would like to explain that they are affixed to certificates on a scale of 100, of which 40 are awarded for a perfect position adjust-

ment, 40 for the capacity of a watch to run at a uniform rate from day to day in any given position, and 20 for a capacity to run without a change owing to ordinary changes of temperature. The table shows, therefore, that in two of the four years' trials one of the American companies entered watches which were the very best in performance of all the watches entered, and that the watch showing the highest record of any entered, was one of American manufacture. I quote these results as conclusive evidence that by the American system of machine watchmaking, watches may be, and are produced, having all the fine running qualities of the best watches made under the ordinary system at a much greater cost.

DISCUSSION.

Mr. Whipple said, that having had an opportunity of testing some of the watches made at the Waltham factory, he could bear out the statement as to their excellent going qualities. The scheme for giving marks indicating the value of watches as timekeepers was the same at Kew as at Yale, and he had to thank Dr. Waldo for the great assistance which he had rendered in the elaboration of the present system. He believed the system was very closely analogous to that which had been employed for many years at Geneva, with one exception, viz., that at Geneva and Neuchâtel monetary prizes were awarded for watches which obtained the highest number of marks. In England, watchmakers had become alive to the necessity of improving the manufacture, and they had come to the conclusion that there was some little good in rating watches and having them certified, though at the outset they ridiculed the idea. He knew of an instance where a customer had been told that a Kew certificate was worth nothing at all, as it did not mean the watch would go well; but upon the customer pressing for a certified watch, he found that the certificate added fifty per cent. to the value. Another difference between the Yale and Kew rating in the adjudication of marks, was that at Geneva a greater proportion of marks were given to accurate compensation. Dr. Waldo and several horologists had given it as their opinion that the attainment of practically correct temperature compensation was comparatively easier than the attainment of correct rating in position, and his experience tended in great measure to confirm this. Many more watches failed to obtain certificates on account of their not going correctly in varying positions than on account of variation in temperature; and the art and mystery of compensating for temperature appeared to be very well mastered by the makers who sent their watches to Kew to be certified. With regard to making watches by machinery, he might mention that this was now done at Coventry, though whether successful from a financial point of view he was unable to say. He had been told by one of the managers that in one wing of the factory watches were being made by hand, and in another by machinery, with a view to a comparison being made of the relative cost of production by hand and machinery. Many parts of a watch must of necessity be better made by machinery than by hand; but other parts, such as screws, could be turned out at less cost by hand by the operatives, as the number required was not sufficient to pay for machinery. As the escapement wheel required to be made to the greatest nicety, it could in all probability be made much better and more cheaply by machinery than by hand. Considering the large number of persons of the lower classes who were out of employment, and whose services could be obtained at a cheap rate, he doubted whether it would be a profitable speculation to erect machinery in England for turning out screws.

Mr. H. Ganney, speaking as a practical watchmaker who had been at the Waltham factory eighteen years ago, and as one who had written and lectured on the subject, said he hoped the outcome of the reading of this paper would be something practical for the art in general, and also to watchmakers in particular. No doubt England had lost a good trade, and for this they had to thank the British Parliament, which, in 1843, refused to grant a charter to a company for the manufacture of watches by machinery. Ingold, to whom reference had been made in the paper, after passing his time between England, America and Switzerland, died almost unknown, but one of his machines was still to be seen at the

factory of Messrs. Gillet and Bland, at Croydon. Watches were now made in London by Mr. Nicholl, by means of machinery, and also by Mr. Gee, who employed over 200 men, and it would be many years before the Americans would be able to turn out watches to equal these. There were two ways of looking at a watch, first, as a work of art, and next, as a piece of commerce, and his own opinion was that they had not yet seen all that could be done in this direction. However great the success of the American companies, they had not yet surpassed the watchmakers horologically. Neither did they put such beautiful work into their watches as would be found in an English watch. He could not agree with Mr. Whipple that it would not pay to make screws by machinery on a large scale if you only wanted a few at a time, because he knew as a matter of fact that it did pay. On behalf of the Clerkenwell watchmakers, he acknowledged that they were under great obligation to the Waltham Company for what they had taught them, and thought that if they were sensible they would take the lesson to heart and endeavor to beat the company.

Mr. Bedford begged to call attention to the fact that, in speaking of the factory at Waltham, Mr. Ganney was speaking of what he knew eighteen years ago. Of course, in the present age, eighteen years was almost like a century, as things changed so rapidly. The factory and machinery which was there eighteen years ago was now all gone.

Mr. Ganney said that Mr. Dennison, of the Waltham factory, was now in Birmingham, and had been there eighteen years, and he established a factory in England sixteen years ago.

Mr. Robert Bragge (Secretary of the English Watch Company) was extremely gratified to find that thanks were given to those to whom they were due, and that at last the labors of Mr. Dennison had been acknowledged. The reason given by Dr. Waldo for the enormous strides that machine watchmaking was making in America was the true one, that the people there found themselves face to face with necessity, besides being unencumbered by tradition. It was a new field, and they entered upon it and went ahead; but in England they were not so happily placed. If there was one disadvantage under which workmen were placed, it was that of holding too much to tradition, from which it was extremely difficult to emancipate them. They made watches as they did for the same reason that the Dutch built their boats, viz., because their grandfathers had done so before them. In Birmingham, there was a factory which turned out a considerable number of watches by machinery; and it was only by the application of machinery, and following on the lines that had been indicated that evening, that watchmaking could hold its own in England. The company with which he was connected had sent a good many workpeople to America, but up to the present, they had not had the chance of sending any watches, owing to the heavy import duty; but he had no doubt that by-and-by they would be able to do even this. In conclusion, he begged to offer his tribute of admiration for the extremely fair and candid spirit displayed in this paper, and hoped that it would spur Englishmen up to a spirit of emulation, and lead them to achieve similar feats to those which had been accomplished in America.

Mr. G. William Frodsham (Parkinson and Frodsham) thought that the thanks of all watchmakers were due to Dr. Waldo for having given them such a clear insight into the industry of watchmaking by machinery in America; but the system was not quite unknown to English manufacturers. He had just made the model of a machine for making ordinary watches, which he intended to take out a patent for in America as well as in England. When American watches were first introduced into England, he made the remark that he was very glad the Americans were undertaking to supply the millions, because it would give English makers time to devote to the manufacture for the hundreds, that was to say, the aristocratic watches, and he saw no reason now to depart from this view. Reference had been made to an English company which did not succeed in consequence of the opposition of Parliament; but this was, no doubt, owing to the fact that in those days there was a strong prejudice, more particularly on the part of workmen, against the introduction of the machines designed by Mr.

Ingold, so much so that at one time this gentleman went in fear of his life, and no doubt the views entertained by the watchmakers and workmen influenced members of Parliament, who, of course, had no technical views upon the subject.

Mr. Liggins said that for a large numbers of years the English public had not been able to get a well-made, good English watch, except at a high price, and therefore, it was time that English manufacturers began to bestir themselves. No doubt many would recollect that some forty or fifty years ago a public company was attempted to be got up for the manufacture of watches by machinery by Mr. Barwise, of St. Martin's-lane, but it was found impossible to work the company, owing to its being opposed tooth and nail by watchmakers and working men. He had not seen a watch factory in the United States, though he had in other countries, and he could bear testimony to the correctness of the statements made with regard to them. He considered it a dire misfortune for the English public and the trade of the country that the export in watches was falling off. As a rule he did not think this applied to high class watches, for it was generally found that when a colonist visited this country he took back with him a first-class English watch; it was the trade in cheap watches that was being lost. For rough usage a machine-made watch had many advantages over a hand-made watch, price and quality being considered.

Mr. Glasgow thought that a good many of the remarks which had been made that evening had been of a personal nature, and not in elucidation of the paper. Dr. Waldo had read a paper which had been highly appreciated, in which he had not introduced any controversial subject. Having done the Horological Institute the honor of calling upon them the previous evening, he said, "This is what we want in America," which he (Mr. Glasgow) took as a compliment to England. It was supposed by some people that watches were all made by hand, but this was a fallacy, there not having been a watch made entirely by hand for centuries. The question to be considered was, how far could machinery be adopted with advantage to the great watchmaking community of the country. If there had been as many watchmakers in the United States as there were persons in that room, watchmaking by machinery would not have existed; it was the necessity that caused it. On behalf of the watchmakers in general, he expressed his gratitude to Dr. Waldo for his interesting paper. There was one remark in the paper with which he could not quite agree, viz., that the workpeople were "machines." Was it by machines that watchmaking had been brought to its present state of perfection? Were the great watchmakers of France "machines?" If so, watchmaking would not be what it was at present. They must not conclude that because the cheap grade of watch was made by machinery, that machinery would do everything. He believed that watchmakers were very much pleased when the system of testing watches at Kew was first established; but there was one practice which they did not appreciate, and that was this, that when a man made a first-class watch, and received a certificate for it, the certificate could be changed to any other person on the payment of 1s. This practice, he thought, was not conducive to the interests of watchmaking.

Dr. Waldo did not believe there was anyone who had been a student of theoretical horology who had a higher appreciation than himself of the genius of the distinguished men to be found in the list of British horologists. There was no finer record to be found than the names of Harrison, Earnshaw, Reid, Dent, Frodsham and others, but he had not intended to present the scientific side of horology; it was merely the great art of making timepieces for a gradually growing civilization over the large world that he came to speak about. That was the question to be considered, and not the question of absolute science of precision in timepieces. The question which the Americans were facing was that of making watches which should keep time at the lowest possible price. He did not know that there were any questions which required an answer at his hands, and he would conclude by thanking the meeting for the kind way in which it had received him.

The Chairman, in proposing a vote of thanks to the reader of the paper, re-

ferred to the extreme interest of the subject, and the admirable way in which that interest along many lines had been developed. The question of the watch was really one of national importance, and there were even interesting side issues which almost rose to the height of political economy, in connection with the manufacture of such an article under new conditions, as opposed to its manufacture under old conditions. It was clear that the sense of the meeting was that England did lose once upon a time a very fine opportunity of expanding the watch trade, when the indications of science were pointed out a good many years ago. He thought that was not only true of the watch trade and of England, but it practically must be true of all trades and in all countries. His interest in the paper had come from the very great interest he took in the more scientific side of the subject, of absolutely accurate time-keeping, and his knowledge of the very great interest which Dr. Waldo had given to this matter. They must not forget in the large political questions the question which always ought to be before anyone interested in a great industry, viz., what can science do to improve it. That would yield to no question in importance. There was still room for the introduction of science into watchmaking in this country, whether the establishment of large companies was insisted upon or not. One of the most interesting parts of the paper to his mind, was the statement of the different scientific processes carried on under one roof; and it was not only the watch, but science generally which would gain in all these localities. With regard to the watchmaking industry at Coventry, he might say that many years ago he was asked to distribute the prizes at the Science Schools in that town, and he then had to tell the people frankly that if there was a little more science teaching in Coventry, it would be better for the watchmaking carried on there. That remark did not apply alone to Coventry; it was applicable to many other places. It was in this direction that the extreme value of meetings like the present would be found, for not only did it enable them to see what had to be done, but it furnished the key of the citadel which had to be attacked in the future.

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## THE SELF-INDUCTION OF AN ELECTRIC CURRENT IN RELATION TO THE NATURE AND FORM OF ITS CONDUCTOR.

By Professor D. E. HUGHES, F.R.S., President.

Inaugural Address delivered before the Society of Telegraph Engineers and Electricians.

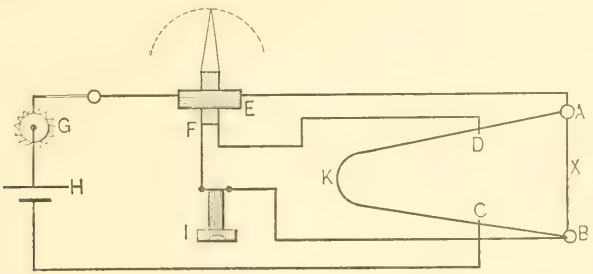
Induced or secondary currents in a near but independent circuit were discovered by Faraday in 1831; and the phenomenon of the self-induction of an electric current in its own wire was observed by Henry in 1832, and traced to its cause in 1834 by Faraday, who proved that on sending a current through a wire a momentary induced current in the opposite direction is evoked in its own wire; also that, on the cessation of the primary current, a second induced or "extra current" is excited in the direction of the primary. The effect is greatly augmented when the wire forms a coil, as we then have in addition the reaction of superposed currents; but the effect exists to a great extent even when the wire forms but a single loop, or a straight wire with the the earth forming the returning portion of the loop, as in all telegraph lines. It has been generally supposed that the nature or the molecular condition of the metal through which the primary current passed exerted no influence upon the extra currents except that due to its resistance. I have previously pointed out that for induced currents "the rapidity of discharge has no direct relation with the electrical conductivity of the metal, for copper is much slower than zinc, and they are both superior to iron." This led me to make a study of these extra-currents, for which purpose I constructed a special induction bridge, in order to measure both the primary and its extra cur-

rents separately at the instant of action.

INDUCTION BRIDGE.

This instrument is a combination of a portion of my "induction balance," with a "Wheatstone bridge." The resistance of the wire is measured and balanced by the bridge; the induced or extra currents are measured and reduced to zero by an equal opposed induced current from the induction balance.

The diagram herewith shows the electrical communications. The bridge consists of a single German silver wire (0.25 mm. diameter, 1 meter in length, of 4 ohms resistance) running from A to K, returning to B. The wire is stretched and sustained upon two wooden arms articulated at K, by means of which the terminals A B can be more or less separated as desired. The wire to be tested, X, is joined at A and B, thus completing the closed circuit of the bridge. The




external communications are shown, A being connected to the primary coil of the sonometer E, and through it to the spring of the interruptor or rheotome G, the interrupting wheel being connected to the battery H, and thence to the bridge at C. The wire from B passes through the telephone I to the secondary coil F, returning to D. Great care has to be taken in the construction of the bridge, so that it shall be as free as possible from induced or extra currents, and for this reason we cannot employ or introduce resistance coils. The resistance of the wire X is balanced by sliding the communications D and C. It is evident that if all the arms of this bridge are equal in resistance and inductive capacity, there will be silence on the telephone; but if A B be slightly stronger or weaker in inductive capacity, then we may be able to balance its resistance, but not its induction, as we shall then have a slight or a loud continuous sound due to the differential extra currents in the arm A B. These are compensated by the introduction in the circuit of the telephone of an equivalent but opposed induced current from the secondary coil of the sonometer F, the degree of angle through which this coil has turned to produce silence being the degree of force of the extra current. The induction sonometer consists of two coils only, one of which is smaller and turns freely in the center of the outside coil. The exterior coil being stationary, the center coil turns upon an axle by means of a long (20 cm.) arm, or pointer, the point of which moves over a graduated arc or circle. Whenever the axis of the interior coil is perpendicular to the exterior coil no induction takes place, and we have a perfect zero; by turning the interior coil through any degree we have a current proportional to this angle, and in the direction in which it is turned. The valve of the induction current for each sonometric degree was $\frac{1}{2500}$ of the primary current which passed through the wire under observation, the latter being variable at will from .001 to .250 ampère. There is also a reversing key (not shown in the diagram), in order to place the interruptor on the telephone circuit and close the battery current from H to A; the conditions then being the usual method of testing, except using the telephone in place of a galvanometer—a well-known method. The telephone, being exceedingly sensitive and rapid, is most suitable, whilst a galvanometer would be too slow, and its use, in fact, impossible for the researches I have been making. Numerous details have been necessarily omitted in this rough sketch of the instrument. Suffice it to say that it is perfectly adapted for the object

sought—viz., the investigation and measurement of the self-induction which takes place in all wires.

By all previous methods the measurement of the resistance of a wire is taken when the current has been already some time in action, or, to use an expression of M. Gaugain, when the electricity has arrived at its "stable period." In telegraphy, electric lighting, and all applications using rapid electrical changes, another period has to be considered, viz. that during the rise and fall of the current; this he named "the variable period," and it is in this period that all the phenomena of induction take place. To observe the stable period, the current is continuously passed through the bridge (and consequently through the wire under observation), and the interruptor being placed in the telephone circuit allows us to find the exact resistance of the wire, free from all induction or change in the wire itself. To observe the variable period, the interruptor or rheotome (making at will from 10 to 100 contacts per second) is placed on the battery circuit, the telephone being joined as shown in the diagram. By means of a switch or reversing key these changes are made as rapidly and often as desired. If there were no static or self-induction, no loss of time, or change of resistance, then the result from these two periods would be equal; but this is never the case, for we find that when the resistance is balanced to a perfect zero for the stable period, loud sounds are given out in the variable period, requiring a fresh adjustment or balancing of the resistance of the wire, as well as a compensating opposing induction current from the sonometer to balance the self-induction. If we balance the resistance or the extra currents alone there is no possible zero, but when both are compensated we find at once a perfect zero for the resistance of the wire, and for its extra currents.

### INDUCTIVE CAPACITY OF METALS.

The results of the following experiments prove that the force and duration of the extra currents depend upon the kind of a metal employed as a conductor, its molecular condition, and the form given to the conductor, independent of its resistance or the electro-motive force of the primary current. The increase of force by increased length is proportional to the length of wire less its additional resistance, but with wires of the same length increased cross section or diminished resistance does not produce a corresponding increase in the electro-motive force of the extra currents. The time of charge and discharge of the wire is independent of the electro-motive force of the extra currents; for, if we compare currents of equal electro-motive force obtained from copper and iron, it will be found that the duration of these currents in wires of 1 mm. diameter, will be seven times slower in iron than in copper, and a still greater difference will be found in larger wires. The longest or slowest charge and discharge take place in the purest soft iron, and have a constant ratio of increase with increased diameter of the wire; my experiments giving for wires of double the previous section, or for wires of four times less resistance, a mean increase of three times its previous duration. The electro-motive force of the extra current in different metals will be seen in the following table, and in order that the values obtained from the sonometer may be clearly understood I have reduced the results to comparative values. The table of values were obtained on wires of similar length, having been repeated on a similar series of lengths ranging from 10 cm. to 5 meters. The instrument is sufficiently sensitive for pieces only 10 cm. in length, and the results from the short lengths were as pronounced and accurate as those for greater lengths. I may add that the instrument shows no effects or traces of static charge for the lengths mentioned.

TABLE I.—*Wires 1 mm. in Diameter, 30 cm. in length.*

| | |
|---|---|
| Soft Swedish iron | 100 |
| Soft puddled iron | 78 |
| Swedish iron, not softened | 55 |
| Soft cast steel | 41 |
| Nickel* | 34 |
| Hardened cast steel | 28 |
| Cobalt* | 24 |
| Copper | 20 |
| Brass | 13 |
| Zinc* | 12 |
| Lead | 10 |
| German silver | 7 |
| Mercury* | 2 |
| Carbon* | 1 |

* Being unable to procure wires of these metals, they were tested in the form of strips, and compared with similar strips of copper. Mercury was in a glass tube 2 mm. in diameter; carbon tested in the form of electric light carbon from 3 mm. to 10 mm.

The above table is only true for wires of 1 mm. diameter, as the effect depends upon the size of the wire in relation to the nature of the metal. In soft Swedish iron a diminution in the electro-motive force of the extra currents takes place with each increase in its section, and this has been partially foreseen by Maxwell, who said: "The electro-motive force arising from the induction of the current on itself is different in different parts of the section of the wire, being in general a function of the distance from the axis of the wire as well as time." From this I expected that the increase of electro-motive force by an increased section would not increase directly as its sectional increase; but I was not prepared to find, as my experiments prove, that after a certain maximum diameter of wire has been reached a marked decrease in electro-motive force takes place with each further sectional increase, and that this maximum is variable with each metal.

When these values are graphically represented, the diagram shows a rapid rise of force in soft iron from an extremely fine wire of 0.10 mm. section to a maximum at 1 mm., from which point there is a slow but continued decrease of force with each increase in the size of the wire, until at the comparatively great diameter of wire of 10 mm. the force is but a fraction more than in the extremely fine wire. Hard Swedish iron has a less initial force in the fine wire, and does not arrive at its maximum until the wire has 3 mm. diameter, being then nearly of the same force as soft iron of the same diameter; the fall from this point is somewhat similar, but less than soft iron, until 8 and 10 mm. soft and hard iron have absolutely the same values. A curious change of values at different diameters is seen in copper and brass. Copper, having nearly double the initial force in fine wires, arrives at its maximum at 4 mm.; but brass creeps slowly up, passing copper at 5 mm., arriving at its maximum at 6 mm., and finally in the large section 10 mm., it has more force than copper, their positions being completely reversed. I have been unable to obtain wires of different diameters of other metals; but zinc rods of 10 mm. gave a still higher rate than brass, whilst in small diameters its force was less. For non-magnetic metals it is probable that the greater the specific resistance of the metal the greater will be the diameter of the wire before the fall commences. Carbon is remarkably free from self-induction, and although there is a rise of force in rods of 3 mm. to 10 mm., it is so small as to be hardly measurable. German silver rises with comparative rapidity, indicating that with wires of 20 mm. its force would equal that of copper. Carbon, therefore, seems peculiarly adapted as a resistance when used in the variable period of electric currents.

### INFLUENCE OF PARALLEL CURRENTS.

The instrument being well adapted for showing the slightest change in the self-induction by the reaction of one portion of the current upon the other when in the same direction, as in a coil, or in the opposite direction, as in a parallel return wire, I made a series of experiments in order to observe the influence of different metallic conductors in this respect. Two silk-covered iron and copper wires of similar diameter and length (1 mm. diameter, 2 meters in length) were each formed in a single loop of 66 cm. diameter. The extra-currents from iron were, as usual, six times stronger than those from a similar loop of copper. On closing the loop by bringing the opposite sides in close proximity, and thus making a parallel return wire (the current ascending on one side and descending on the other), I found that the reaction of currents in opposite direction was very different with different metals, the results depending more upon the nature of the metal than upon the proximity of the wires. There was a reduction of the previous force of the extra-currents of iron, when forming a parallel return wire, of 15 per cent., whilst the reduction in copper was 80 per cent. Thus the currents in copper are far more influenced by an external wire than those in iron; consequently, a telephone line having its return wire in close proximity should invariably be of copper, as not only is its specific inductive capacity less, but this is again reduced by the return wire, so that its self-induction is far below that of iron. In order to observe the influence of currents in the same direction, the same wires were formed into a close coil of twelve turns of 2 cm. diameter; and from the known effects of parallel currents in

the same direction we should expect a greatly increased effect. It was so in the case of copper, but iron was far less under the influence of an external parallel current; the strength of current in iron when formed into a coil being 57 per cent. greater than that of a single wide loop, whilst in copper the increase was 404 per cent., or seven times the increase of iron; and although iron when in a single wide loop had six times the force of copper, the comparative strength was reversed when the wires were wound as a coil, the extra-currents from the copper coil then having 14 per cent. than that from iron, and this difference could be rendered more evident by employing longer wires. Thus copper, as regards extra-currents, is far more sensitive to the influence of external currents than iron, and the true self-induction from its own current can only be obtained by a straight wire, where the return wire is at such a distance that its influence is not appreciable.

REACTION OF CONTIGUOUS PORTIONS OF THE SAME CURRENT.

It is well known that currents in separate portions of the same wire (as in a coil) react upon each other, and I felt convinced from the preceding experiment that self-induction is entirely due to similar electro-magnetic reactions between contiguous portions of the current in its own wire. Let us assume that an electric current consists of a bundle or an almost infinite number of parallel currents, the limit being a single line of consecutive molecules; then each line of current should, by its electro-magnetic action, react on each of the others similarly to wires conveying separate portions of the current, and the self-induction should be at its maximum when the lines are in the closest possible proximity, as in a conductor of circular section, and far less when separated, as in one of ribbon form, where the outlying portions are separated by a comparatively great distance; there would still remain, in the latter case, the reactions from the near portions on each other, and these should again be reduced by cutting the ribbon into a number of thin, narrow strips, separated, except at their junction, to a sufficient distance to prevent any marked reaction. My experiments prove that this assumption is an experimental fact, for we can reduce the self-induction of a current upon itself to a mere fraction of its previous force by simply separating, as indicated, the contiguous portions of a current from each other, the results proving that a comparatively small separation, such as is obtained by employing ribbon conductors, in place of a wire of the same weight, reduces the self-induction 80 per cent. in iron and 35 per cent. in copper; and if we still divide the current by cutting the ribbon into several, say sixteen, strips (separating the strips at least 1 cm. from each other), then the combined but separated strips show a still greater reduction, being 94 per cent. in iron and 75 per cent. in copper. The following table shows the comparative reduction of self-induction by employing ribbons and parallel separated wires:

TABLE II.

| Flat Strips compared with Round Wire 30 cm. in length. | Copper. | Iron. |
|---|---|---|
| Wire 1 mm. diameter. | 20 | 100 |
| Strips. | | |
| 0.25 mm. thick, 2 mm. wide | 15 | 35 |
| Same, 5 mm. wide | 13 | 20 |
| Same, 10 " " | 11 | 15 |
| Same, 20 " " | 10 | 14 |
| Same, 40 " " | 9 | 13 |
| Same strip rolled up in the form of wire | 17 | 15 |

| Parallel Wires 30 cm. in length. | Copper. | Iron. |
|---|---|---|
| Wire 1 mm. diameter. | 20 | 100 |
| Single Wire. | | |
| 0.25 mm. diameter | 16 | 48 |
| Two similar wires | 12 | 30 |
| Four " " | 9 | 18 |
| Eight " " | 8 | 10 |
| Sixteen " " | 7 | 6 |
| Same, 16 wires bound close together | 18 | 12 |

The resistance of a conductor, or even the nature of its metal, has less influence on its self-induction than the form given to that conductor, the 1 mm. wire in the above table having a less resist-

ance than the strip of 2 mm. wide, and a greater than any of the wider strips; but through all these variations we notice a gradual fall from the wire to the widest strip or ribbon, with a marked return to its previous force when the ribbon is rolled up in the form of a wire. The reduction is greater in iron than copper, but its increase when rolled up is less than copper, thus agreeing with the previous observations on the difference of iron and copper to external reactions. A still greater reduction takes place when we separate a current by using parallel wires separated 2 cm. from each other, as shown in the table. We then have a similar reduction to that produced by cutting the strips into several separate conductors; and we again remark that when the wires are brought close together (forming a stranded wire) copper rises in a far greater proportion than iron, the sixteen fine iron wires twisted together as a stranded wire having 88 per cent. less induction than a solid wire of similar weight; a remarkable fact being that whilst a solid iron wire has an inductive capacity 80 per cent. greater than a solid copper wire, this is completely reversed when each metal forms a stranded wire of the same weight as the solid, for iron then has 33 per cent. less self-induction than copper. It is not necessary to use extremely fine wires when we desire to reduce the inductive capacity of iron to that of copper, for I have formed stranded wire rope of sixteen strands of wire where each wire was 1 mm. in diameter, giving 75 per cent. less induction than a solid wire of the same resistance. I purchased an ordinary wire rope of 6 mm. diameter, having 6 strands of 6 wires, each 0.5 mm. diameter. This gave the best result yet obtained; for on comparing 3 metres of it with a similar length of solid iron wire of the same resistance, the 36-stranded wire had only 5 per cent. of the amount of induction shown by the solid wire. Steel, in the form of ribbon or stranded wires, shows a similar effect to that of iron; and it is a remarkable fact that, whilst the extra currents from a steel or iron wire 4 mm. in diameter are extremely slow, and impossible to balance without reducing the time of the sonometer current (by the introduction of an iron core), the ribbon or stranded wire requires no such compensation, for its feeble extra-current is exceedingly sharp, and can be balanced to a perfect zero, being actually quicker than that of a solid wire of copper of the same resistance, This fact I regard as one of great importance for telegraph lines and lightning conductors.

A curious effect takes place if we employ mixed conductors, such as a compound wire of copper and iron. A fine coating of copper reduces the induction in a solid iron wire in a marked degree. This I found to be due to the difference of electro-motive force of the extra-currents in the two metals, for, by employing a fine copper wire parallel with an iron wire, and in contact at the ends, the extra-current was reduced 60 per cent. The copper wire, having a lower electro-motive force, probably acts as a shunt; but if the capacity of the iron has already been reduced, as in a sheet or stranded wires, then the addition of a single copper strand increases the force, as the electro-motive force of the extra-currents of copper is above that of stranded iron. There has been for many years a discussion as to the merits of the round form as compared with the tape or ribbon form for lightning conductors. Those in favor of the former based their conclusions on experiments which gave a negative or no apparent difference between the two forms of conductors. Those in favor of ribbon conductors, as Sir W. Snow Harris, Professor Guillemin, and many others, based their opinion upon marked differences found when using high charges of static electricity. The latter supposed that there was a difference between discharges of static electricity and voltaic currents of low tension, and that the advantage recognized by almost conclusive experiments was due in a great measure to conduction by surface. In the year 1864, Prof. Guillemin and myself, as members of the Commission de Perfectionment of the French Telegraph Administration, were charged with the mission of testing the comparative methods of the lightning protectors then used upon their lines.

Our method of experimenting consisted in joining an insulated conductor to a short, fine iron wire connected directly with the earth return wire. A Leyden jar battery charged by a Rhumkorf

coil was discharged through this conductor, burning or deflagrating the fine iron wire. This wire represented the telegraph instrument requiring protection, and by placing the lightning protector connected with the earth in advance of the fine iron wire we could observe the amount of protection afforded. This answered extremely well for feeble discharges, but with the full power of our battery the fine iron wire was invariably destroyed, even with the best lightning protectors, which are universally used to this day. Noticing that we could not give absolute protection to the fine wire by lightning protectors, we tried the effect of joining the conductor direct to a separate earth wire in advance of the fine wire, and with powerful discharges the wire beyond the protection was invariably burnt, notwithstanding that we connected the conductor direct to earth by a copper stranded wire of 1 cm. diameter. Professor Guillemin continued these experiments after my departure for Russia, and he found, by employing a thin sheet of copper as a conductor to earth in place of the copper stranded wire placed in advance of the fine iron wire, that the wire could be perfectly protected. The theory of this action was not understood at the time, and the experiment has not received the attention it deserved; but the mutual reactions of contiguous currents shown in this paper explain the phenomenon in the fullest degree, for we see that a sheet or ribbon conductor has far less self-induction than a wire or rod of the same material.

I am fully convinced from the results of my experiments that an enormous retardation or resistance is evident in all conductors at the first portion of the variable period, and that this is due to self-induction, the current thus arousing an antagonist in its own path sufficiently powerful, when the primary current has a high electro-motive force, to deflagrate or separate the wire into its constituent separate molecules, as shown by Dr. Warren de la Rue. It is also evident from my experiments—which are easily repeated, with invariable results—that a flat conductor has far less self-induction than a solid of circular section during the variable period; and even with a constant current, as in the stable period, this form of conductor, as first shown by Professor George Forbes, would, from its greater radiation, convey more current with less heating than a wire or rod of the same resistance. Lightning conductors are intended to convey a current of high intensity during an exceedingly short time, and should therefore be designed so as to convey this current with as little opposition from self-induction as possible; consequently, I regard a solid rod of iron as the worst possible form for a lightning conductor. The conductor, if of copper, should be of ribbon form, say 1 mm. by 10 cm. wide, or, if of iron, of numerous stranded wires or a wide ribbon of similar conductivity to that of the copper.

SELF-INDUCTION OF A TELEGRAPH LINE.

A telegraph line may be considered as a single loop; the earth taking the place of a return wire can only affect the self-induction by a diminution of its effects, as in the case of a parallel return wire. Mr. W. H. Preece has lately read a most valuable paper on "The Relative Merits of Iron and Copper Wire for Telegraph Lines,"* in which he shows, by comparative rates of speed with the same instrument, that on a copper and an iron line of 278 miles in length (between London and Newcastle), whose resistance and static capacity were rendered equal, there was an increase of speed in the copper line of 12.9 per cent. as compared with an iron wire.

I have not been able to test the relative speeds obtainable by telegraph instruments on wires of different material. The results in every case would depend very much on the apparatus employed, but I have considered the question from a point of view independent of the instruments. There is a remarkable difference in the resistance of a wire during the stable and the variable period, the measurements taken in the stable period giving no real or approximate idea of what its resistance really is during the rise of the current in the wire. A curious fact in relation to telegraphy is that all measurements are made during the period of a constant flow of current, whilst all instruments, particularly those requiring rapid changes in the current—work only during the rise and fall of the

* British Association, Aberdeen, September 1885.

current, as in the variable period. Telegraph engineers, however, have not made the mistake of assuming that there is no difference in the resistance of a wire in these two periods, as it is well known that electro-magnets and coils have a far higher resistance during the rise and fall of a current, and coils simply augment the effect of a straight wire of a given length. The present method of testing by Wheatstone bridge has been adopted because we had no practical means of measuring the resistance in the variable period; and I do not believe that this can be accomplished except by a similar method to that which I have used, in which the resistance and self-induction are separately measured and balanced, and by the use of an exceedingly rapid and sensitive instrument of observation, as the telephone, in place of the sluggish galvanometers, no matter of what construction. The speed of telegraph instruments is greatly influenced by the resistance of the wire. I said in 1883* that a great difference could be found in the resistance of an electrical conductor if measured during the variable instead of the stable period, and I have made numerous experiments with the view of ascertaining to what extent this difference would probably be felt on telegraph lines.

I have already mentioned that the time or the duration of the extra-currents increases rapidly with the section of the conductor; consequently comparisons can only be made between wires of similar section for speed, or wires of similar resistance for differences in their variable period. In measuring the resistance of a wire during the two periods, I have found it best to avoid the use of resistance coils, the simplest method being to measure or balance a given length of wire in one period, and then observing how much lengthening or shortening of the wire would produce a similar zero in the second period. Suppose that we commence by balancing the resistance during the variable period, and fix the sliding communications at the point at which we have obtained a perfect zero; we can now change to the stable period by means of the commutator; and we no longer find a zero, but extremely loud sounds, we gradually lengthen the wire under observation until we have again a perfect zero. The amount of wire added to its previous length shows the difference in resistance between a conductor in which there are rapid electrical changes and that wherein the flow of current is constant. Amongt numerous experiments I will cite a single example. I measured or balanced the resistance of an ordinary soft iron wire, 1 metre in length and 4 mm. diameter during the variable period, and found that it required in the stable period exactly 2 metres 58 cm. to balance the previous resistance. Similar tests on a sample of best charcoal iron wire, as used on our telegraph lines, gave still more remarkable results, showing 225 per cent. difference between the two periods; for 1 metre of this wire had, during the rise and fall of the current, precisely the same resistance as 3 metres 25 cm. in the stable period. This shows that an iron telegraph wire has with rapid currents more than three times the resistance during its actual work than that supposed to be its true resistance. It was difficult on short lengths to find any change whatever in the resistance of copper or stranded iron wires in the two periods; the time of discharge being excessively rapid, I could only estimate the resistance by the electro-motive force of the extra currents, or by forming the wires into coils (when a remarkably great difference is shown), and then estimating the proportional amount due to its own reaction; by this method I was enabled to detect 20 per cent. difference for a solid copper wire, and but 8 per cent. for the stranded rope of 36 iron wires. The difference in time of the duration of the extra currents between solid iron and copper and between solid iron and stranded iron is so great that we may consider a solid iron wire to belong, comparatively speaking, to the class of slow conductors, whilst copper and stranded iron would belong to the rapid.

I have shown a difference of resistance in the variable period between copper and iron of at least 200 per cent.—a difference which will be felt on instruments depending upon rapid changes, such as the telephone; and it is evident that the more rapid the contacts of a

* Discussion on the paper of W. H. Preece on Electrical Conductors, *Proc. Inst. Civil Engineers*, vol. lxxv., 1883.

telegraph instrument the greater will be the difference between copper and iron. There is consequently a great electrical advantage in those instruments which require only a single current for each letter, as the economy of electrical impulses allows them to work at a comparatively high speed; the duration of the extra-currents would be shorter than the length of their contacts, and consequently they would perceive very little, if any, difference between the two periods, or between iron and copper. If we use three or five currents for each letter, we must necessarily send them faster or closer together; and the difficulty increases in a rapid ratio with the speed of intermittent or reversed currents, until a point is reached (as I have shown in the case of best charcoal iron) where, whilst nominally working through 500 miles, we are practically working through an equivalent resistance of at least 1,500 miles, and this without taking into account the static charge, which would, in addition, from its comparatively extreme slowness of charge and discharge, cause the apparent resistance of the wire in the variable period to be much greater than I have mentioned. In Mr. Preece's experiments he finds a difference of speed of 12.9 per cent, between iron and copper, which is far less than the difference of resistance during the variable period which I have obtained; and this may be explained by assuming that the speed of the reversed currents which he employed was only near the border land of extra currents. I am convinced that if Mr. Preece could have increased the speed of the instruments he would have found a far greater difference between iron and copper; and if I regard the results of a solid iron wire alone, I should consider iron as unsuitable for telegraph instruments requiring extremely rapid currents. Copper would reign supreme it were not for the fact, which I have discovered, that stranded iron wires have even a greater rapidity of action than copper.

### PHYSICAL CHANGES IN THE CONDUCTOR.

Self-induction not only depends on the nature and form of its conductor, but also on the physical state of the metal, as already shown in the case of soft and hard iron. I felt convinced that the higher force in iron was due to its magnetic capacity, and to prove this I tried the effect of heating the wire to a bright red heat, or 1000° cent. It is well known that iron loses its magnetic properties at bright red heat, and I found that its self-induction then fell to less than that of copper. This would have been conclusive had it not been for the fact that a different result takes place when the capacity of the iron for self-induction has already been reduced, as in the case of thin flat sheets of iron. In this case there is no disappearance or further decrease of induction except that due to the extra resistance caused by the increased temperature of the strip. Now, as the strip was highly magnetic when cold, and lost this property at red heat, there should have been some change in its self-induction if this were due to the magnetic nature of the iron alone. This requires further researches before a probable explanation can be given. Iron is peculiarly sensitive to all physical changes. Mechanical strain of all kinds hardens the wire, and its influence on its self-induction can at once be detected. An iron wire under a moderate longitudinal strain loses 40 per cent., and its capacity is then less than unstrained cast steel. Iron well annealed has much less resistance than the same iron when hard drawn, and soft iron is generally employed for telegraph lines; but during the variable period a curious reversal takes place, as then soft iron has a higher resistance than hard iron. This apparent anomaly is easily explained if we compare the far higher self-induction of soft iron. Work is done at the expense of electrical energy, and the apparent higher resistance is due to the greater electro-magnetic action in soft iron. An iron wire shows traces of remaining circular magnetism after the passage of a continuous current, reducing the following extra-currents 10 per cent. Magnetising the wire, or subjecting it to mechanical vibrations, when used separately, produce no apparent change in its inductive capacity, but a remarkable change takes place if either of these is used in conjunction with a constant current. Let us pass a constant current and heat the wire to red heat, allowing it to cool with the current on; or, in place of heat, magnetise the wiire,

or, in place of magnetism, give the wire mechanical vibrations—the result of either of these being a strong internal circular magnetism, due, I believe, to the loosening of the magnetic molecules, allowing them to rotate with greater freedom under the influence of heat, mechanical vibrations, or magnetism. A wire thus treated has no longer its previous self-induction, which has fallen 60 per cent.; and as the circular magnetism becomes fixed when the vibrations cease, this molecular structure remains a constant as long as we employ intermittent currents in the same direction, but the structure disappears the instant a revere current is sent; and this explains why we have more than double the amount of self-induction from reverse currents, as each reversal destroys any remaining magnetism due to the previous passage of the current.

If we compare the electro-motive force of self-induction on a given length of wire with the secondary currents generated in a second but independent circuit, we find that the self-induction is the most powerful, the secondary currents generated in a close independent copper wire being 20 per cent. less than its own wire. There is no difference between the self-induction of a current and the secondary currents; they are, in fact, as proved by Faraday, part of the same phenomenon. The self-induction is evidently due to the electro-magnetic reactions of the primary current, and as magnetism permeates space, the separation of the wires only serves to insulate the primary, but does not affect its magnetic influence; and, as I have shown in the reactions of contiguous portions of the same current, so the magnetic reactions perpendicular to the axis of the current continue through the wire to all surrounding wires; and if we call the currents in the independent wire secondary, they are still secondary whilst enclosed in the wire of the primary; and as the reaction will ever be the strongest in the axis of the current, so will these currents be necessarily stronger than those induced in independent wires. For this reason we should be able to obtain extra-currents of far higher electro-motive force than would be possible from a secondary wire of the same length. It was my intention, on the reading of this paper, to demonstrate by practical experiments some remarkable properties of extra-currents of high electro-motive force; but I find that the subject and apparatus employed require a longer description than the limits of this paper allow. I must also leave aside for the present my experiments upon coils of different forms with cores of different metals. These, as well as other results obtained, indicate that there is a large field of useful research in many directions, each, however, requiring special studies according to the object we may have in view. The record of numerous experiments, of which this paper is only an abstract, shows that the nature of the metal as well as its physical condition has an important influence upon the self-induction of an electric current, and by a study of the reactions produced by the contiguous portions of a current, and by application of the results, we may, as in the case of iron, transform an extremely slow conductor into one of the greatest rapidity. I therefore hope not only that these researches may be of interest from a scientific point of view, but that the results obtained may be of practical utility in some of the numerous applications of electricity.

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## THE LIMIT OF SPEED IN OCEAN TRAVEL.

By R. H. THURSTON.

From "The Forum."

The questions are often asked: What are the causes which limit the speed of ocean-going steamers? Where are we to look for more favorable conditions than those now existing? What may we expect in the immediate future, and what, ultimately, as to the limit of increase of speed in steam navigation? The questions are easily asked, but, like many such problems, they will be readily seen to admit of no definite answer. No one can forecast the future in this age of multiplying inventions, of growing capacity on the part of the engineers to cope with

nature and to force her to give aid in conquering her mightiest opposing forces, and of continually-occurring victories of science and art, the one aiding the other, over apparent impossibilities, in every department of human activity. But we may at least feel our way somewhat beyond the present limit of our advance, and may, by careful study of the problem, and consideration of the principles of science and methods of art known to us, get some idea of what is before us.

The speed at which a ship can be driven through the water depends upon many, but well-known, conditions, the laws governing which have been, for the purposes of the naval architect, very well determined. Given the size and form of any well-designed craft, it is easy to predict, with a fair degree of approximation to accuracy, what amount of power will be demanded to drive the vessel at any proposed speed. This being known, it is easy to ascertain the size and form of the engines and boilers required, and to calculate their weight, bulk, and fuel consumption. It would thus seem that no unknown elements enter into the problem, and that a precise answer might be easily given to the question. That is not the fact, however, and it will be presently seen that there are very important factors, the value of which, and sometimes the nature of which, are not, and cannot as yet, be exactly known. It is proposed in the following paragraphs to consider the elements of the problem, and to discover where these uncertainties lie, to what extent they obscure the subject which we have taken up for study, and, so far as is possible, to obtain some idea of the extent, as well as the character, of the limitations which they involve.

The resistance of a steamship or other vessel consists of two principal parts. The effort required to overcome the friction of the water on its "wetted surfaces" measures the one, and the force expended in producing the waves that are seen arising about every ship in motion constitutes the other of these two quantities. Of these factors, the first is by far the greater in all well-formed ships, and such alone can be considered here. For every ship of a proposed size and weight there is a certain form and proportion of hull which is known to be best for the intended speed, and hence there is no great difficulty in securing almost exactly the best possible form, and thus of eliminating avoidable "head-resistance," or "wave-making" resistance, as the smaller of the quantities is termed. The friction of hull may be calculated, also, very approximately, as it is found to be very nearly proportional to the area of wetted surface. It is thus smaller as the surface of the hull below the water line is smaller. But it is evident that the nearer the form of the ship approaches that of a hemisphere the less must be the resistance due to friction, and that between the latter shape and that elongated and graceful form which gives minimum head resistance there must be some intermediate form which will give the least total resistance. The form of minimum resistance for a given size of ship must usually be felt out by careful experimental work. The solution of the problem last stated is, then, one of the elements of the problem of larger extent, that of maximum speed on the ocean. This solution is in process of being effected, and may be considered as having been already obtained with fairly satisfactory accuracy. The Oregon, now famous both for her speed and for her sad fate, and even more satisfactorily, perhaps, the "America," represent very excellent illustrations of highly successful attempts at a solution.

The power demanded to propel any vessel at ordinary speed varies as the square of her length nearly, or as the area of the transverse major section, and as the cube of the speed. Thus, to double the speed of any vessel requires eight times the power demanded at the lower velocity. Two vessels being of equal speed and similar form, but the one of twice the length of the other, the second will require four times the power of the first. The second vessel, however, carries eight times as much weight, and the power per ton of vessel is one-half as much as would be demanded by the first, if driven at the higher speed. These principles are modified by the relation of form to speed and size, and the rate of variation of increasing resistance of a badly-formed ship is greater than above stated; while, on the contrary, the well-formed ship may, at very high speeds, meet with a resistance which increases at a lower rate than the stated

law indicates. For vessels loaded to a limit with machinery, the higher the speed demanded, the larger must be the ship.

The impelling power of the ocean-going steamship is supplied by engines that have now become well fixed in their general forms and proportions, although signs of another revolution are already plainly discernible. The standard form of marine engine for merchant ships is a machine having its steam cylinders set vertically. It is of the "compound" type, *i. e.*, so arranged that the steam taken from the boilers is worked expansively to lower pressure in one cylinder, is then "exhausted" into a second larger cylinder, in which it is further expanded, doing work, meantime, until it falls nearly to the pressure of the condenser, and is then exhausted into the condenser, where it is condensed and returned thence into the boiler to be again evaporated. The condenser is called a "surface condenser," because the condensation occurs on the interior surfaces of the apparatus, which are kept cool by the flow of water along the opposite side of the metal.

The boilers supplying the steam to the engines of ocean steamers are usually of the Scotch type, consisting of a drum-shaped vessel, containing the furnaces and flues, or tubes, in which the fires are kept burning, and through which the flame, smoke and gases pass to the smoke-stack, heating the water contained in the boiler as they move over these heating surfaces of sheet iron, which surfaces are, on their opposite sides, in contact with the water to be made into steam. The larger these boilers the more economical are they, but the less powerful for their weight. Increased economy is always obtained at a sacrifice of power. Increase of speed thus means decreased efficiency.

The steam furnished to the engines will be used with greater economy as its pressure is greater, because it is worked with greater expansion as the speed of the engine is greater, and as the wastes, some of which are more or less controllable, are more effectively provided against. There are two great sources of waste—the one the unavoidable waste which occurs in consequence of the fact that the steam must be exhausted from the engine at such a temperature, and in such physical condition as to carry away a considerable amount of heat, partly sensible, and partly unrecognizable to the senses, and hence called by James Watt and Dr. Black, who discovered it, "latent heat"; the other is that waste which is due to the circumstance that all parts of the engine are made of metal, and therefore have high conducting power, and thus, by a process of storage and waste which is very interesting to the engineer, but which cannot be here described, often cause the loss of as much heat as is usefully applied. The first method of waste, in good engines, will often lead to the loss of three-fourths of all the heat of the steam that is supplied to the engine. The enormous waste to which the steam-engine is thus subject is reduced by steam-jacketing—by the covering of the engine cylinder with a jacket in which steam from the boiler is kept, in order to sustain the temperature of the internal surface of the engine—by superheating, and by high speed of the engine. The direct means of securing economy are increasing the steam pressure, with corresponding increase of the range through which the steam is expanded, and the reduction of losses of power in the engine and its machinery of transmission, including the screw propeller. The extent to which these several means of rendering the engine more effective and economical and useful, largely determines to what extent gain of speed at sea can be secured. It is further evident that the lighter and stronger the engine and boilers can be made, the higher the speed of vessel attainable. It has been often proposed to replace steam by some other fluid; but it is well known to men of science that the gain to be anticipated is theoretically *nil*, and engineers familiar with the steam-engine are well aware that not only are there no practical advantages of importance to be gained, but that many decisive practical objections exist to every other known fluid yet discovered and used in a heat-engine, in competition with steam.

The present state of the art may now be perhaps understood, and the probabilities of important advancement during the next generation may possibly be gauged with some degree of satisfaction.

The steamer Oregon, of which the name is now as familiar as as household word, may be taken as representative of the condition of the art at the commencement of the year 1886. She was a vessel of about 7,500 tons measurement, of 12,000 horse-power, and could, in a smooth sea, make about 20 knots (24 miles) an hour. The trip across the Atlantic was made in less than six and a-half days. Her length was 500 feet, breadth of beam 54 feet, and depth of hold 38. The America, a less noted, but no less wonderful vessel, is of 6,500 tons burden, 9,000 horse-power, and of very nearly the same speed. The smaller ship would seem to be the better illustration of the highest success in this direction. The Servia is 530 feet long, 52 feet beam, 44½ feet depth, and of 8,500 tons burden. Her power is nearly equal to that of the Oregon, and her speed something less. A still later example of the best modern naval architecture is the Etruria, a ship of 520 feet length, 57 feet beam, 41 feet depth, and 8,000 tons measurement. Her speed is about the same as that of the Oregon, but she is a larger, steadier, and perhaps better ship. Ten such ships placed stem to stern, as will be seen, would form a line one mile long.

But the most extraordinary performances, from the point of view here taken, are those of the steam-launches and torpedo boats built in the United States and Great Britain within the few years covered by the construction of the ships just described. The Herreshoff yacht, Stilletto, made more than 25 miles an hour not long since, and "showed her heels" to the Mary Powell, the fastest river steamer, probably, in the world. A torpedo boat built for the British Navy has made 20.14 knots an hour, and another 21 knots, while still another is reported by its builder, Mr. Thorneycroft, to the British Institution of Civil Engineers as having made 22.01 knots (25½ miles) an hour. These little craft are but 80 to 100 feet long, and of but 30 or 40 tons weight, including hull, machinery, and all. Their performance has excited the wonder of engineers as being enormously beyond anything yet attained by the larger vessels, the difference in size being considered.

Without attempting to assign a limit to the progress of naval construction in the coming years, we may be permitted to ask what might be done with a ship of a size now regarded as perfectly practicable, giving it the lines now regarded as the best for its maximum speed, a hull of minimum resistance to the flow of the water past it, and driving it by engines equal in economy, power, lightness, and general efficiency to the best yet designed and applied, and availing ourselves of every known means of securing the best result in the attempt to attain the highest velocity possible by these familiar methods, while yet retaining the conditions demanded of the fast transatlantic steamer.

It was asserted by a distinguished man of science, forty years ago, that no steamship could be made to cross the Atlantic, because of the impossibility of carrying sufficient coal to supply the engines and boilers for the voyage. The prophecy was proved false almost as soon as it was uttered by the appearance in New York Harbor of the Great Britain, the pioneer of the Cunard Line, after a passage of 14 days and 9 hours, and of the little Sirius beside her. A more credible recent prediction was made by a well-known naval architect, Mr. Robert Duncan, in 1872, who stated that he anticipated that, before the end of the century, we should see crossing the Atlantic the ferry-boats of the ocean, 800 feet in length. The Great Eastern was 680 feet long, and the difference between that length and 800 feet is not now to be considered very great. Let us assume that such a ship may be constructed, the question arises, what would be her maximum possible speed?

A steamer 800 feet in length, 80 feet beam, and of 25 feet draught of water, would weigh, complete and in sailing trim, about 38,000 tons, if given what may be considered as the best form to-day known for maximum speed. The fast ships of to-day exert about one and a-half horse-power per ton to reach a speed of 20 sea miles an hour. With some little improvement, such as may be safely anticipated before the close of the century, this figure may be reduced somewhat, and a larger ship will have some advantage. Our later Leviathan may be expected to demand about 35,000 horse-power at 20 knots. We will, however, aspire to 40 knots (about 47 miles), or a

speed of nearly one statute mile per minute. At this enormous speed she would cross the Atlantic in about 80 hours, or less than three and a-half days. The power requised would be calculated to increase as the cube of the speed; but it is, in fact, found that the law often becomes more favorable at these higher speeds, while a speed of 40 knots ecomically corresponds, according to what are known as "Froude's laws," to about the speed of the torpedo-boats, which latter are found to have reached a velocity well beyond the point of change of the ordinary law of resistance. We may take the probable power demanded as not far from 250,000 horse-power.

The weight of the steam machinery of vessels of various classes varies greatly, the maximum being several hundred pounds per horse-power, and the minimum falling, in the faster torpedo-boats, to a little above 50 pounds, while the yacht Gitana gives a still lower figure, 43 pounds. Progress beyond the latter point must be exceedingly slow, if we may judge by present appearances. These figures are partly attained by the sacrifice of efficiency, and we may perhaps fairly consider 60 pounds as the minimum to be calculated upon for this generation. Our machinery for the new ship will thus weigh about 7,500 tons. The fuel consumed by the most economical of known engines is much less than by the large steam engines of the transatlantic "liners;" but we may take the lowest figure for to-day as a fairly probable figure for this case. This is $1\frac{1}{2}$ pounds of good fuel per horse-power and per hour, or a trifle less; and our ship will burn about 175 tons of coal an hour, 3,200 tons a day, and 10,500 tons for the voyage. The total weight of fuel and machinery will then be about 18,000 tons, leaving 20,000 tons for weight of ship and cargo. The hull of such a steamer, as now constructed, would weigh about one-third the total "displacement," or 12,000 tons. The introduction of steel and the improvements to be effected in construction will probably somewhat reduce this weight; but it is not likely, so far as can be seen to-day, that the reduction will be very great. Eight thousand tons and over are left for passengers, crew, stores, and such valuable freight as may be taken.

It might be questioned whether the propeller of such a steamer could take up and usefully apply such an enormous power; but the experiments already made on torpedo-boats by Mr. Thorneycroft seem, in the opinion of that authority, to settle that point. He calculates that a single screw, of less size than those by which this ship would be driven, would be capable of transmitting the power of engines, "indicating," as the engineer puts it, about 400,000 horse-power.

Our proposed ship may be driven by "twin" screws. It may be asked whether economy is not to be anticipated, and to a very great amount, by the adoption of higher steam pressures. On this question there is no settled opinion among engineers. It would seem, however, that the gain to be anticipated will be very slight, and that a limit will probably be reached soon. Pressures of 150 pounds and more are already adopted in some cases, and the introduction of the "safety" form of "water-tube" boiler will probably soon permit still higher tension; but the gain of economy from this change is now found to be very moderate, and but little is expected from it by the majority of experienced naval engineers, except in decrease of weight of boilers. The boiler problem is exceedingly important; the weight and volume of the steam generator is a great obstacle to further advance. Increase of piston-speed may help us more. The maximum reached at present is about 1,000 feet per minute; but steam will follow the piston at any speed up to more than one hundred times that velocity. There seems no reason to doubt that the adoption of familiar principles in balancing may permit much higher speeds to be attained. The gain to be expected from increased expansion of steam is apparently not likely to be rapid, or to become very great, in the immediate future. Decreased weight of parts by the more extensive use of steel, and perhaps by the introduction of new metals and alloys, may prove helpful; but nothing positive can be said of this as yet. We certainly are not yet in a position to expect much. The gain by improved forms of hull, and by expedients looking toward the reduction of the friction on its exterior, cannot be expected to be im-

portant. Thus the question of increasing the speed of ocean travel seems likely to resolve itself into one of practicable size of vessel, and this means simply a question of cost and financial return. If higher speeds will "pay," higher speeds will be reached by the construction of larger ships. The limit is likely to prove mainly a commercial one for generations, so far as we can now see. To-day the fastest ships do not pay expenses, and the limit is reached in this direction. When more passengers and more precious freight can be found to pay for faster ships, faster ships will be built. The skill and knowledge of the engineer and shipbuilder will keep pace with the demand, so limited, far beyond any point that we can to-day perceive.

The wonderful effect produced by the application of human ingenuity to the development of inventions looking to the subjection of the powers of nature to the purposes of man, is well illustrated by these results of the introduction of steam power for the propulsion of vessels. Some slight idea may possibly be gained of our advancement in this direction, actual and possible, during a single century, by considering what is meant by the application of 250,000 horse-power to the propulsion of the ship here schemed out. The engineer's horse-power is the equivalent of the work of the strongest known horses when working at their usual rate in the ordinary working day. But the average horse is much less powerful, and it is safe to say that one-horse power, in the steam engine, is equal on the average to at least one and a third times the power of a horse. Then, again, the horse cannot work up to his average full capacity longer than about eight hours a day, while the marine steam-engine works continuously, day after day, the whole twenty-four hours, without halt or slacking its pace. Thus the engine horse-power is the equivalent of the operation of four horses, where the work is carried on without interruption. The 250,000 horse-power of the ship of the next century must be taken as the equivalent of the work of 1,000,000 horses. One million horses would weight about 1,000,000,000 pounds, or nearly 500,000 tons —over ten times the capacity of our ship, and nearly seventy times the weight of its machinery. The food and bedding of 1,000,000 horses for a single day would weigh probably 50,000 tons, or more than double the weight the vessel can float. Were this great herd of horses to be formed into a "string-team," allowing ten feet for the lenfith of one horse, and for the "clearance" between each two in the line, its length would be nearly 2,000 miles.

The cost of running the ship above schemed out would be probably not less than $75,000 for each voyage across the ocean; and the passage money of 500 passengers, at $150 each, would be required to pay this. Each passenger would save about four days' time, and four days of annoyance incident to the present method of travel; and this must be the equivalent to him for the increased cost. The ship could make a profit on freight and mails.

It must not be expected that the methods and details of construction which must be learned and applied properly in such a vessel are to be acquired promptly or easily. The problem of proper construction of the engine, or of the propeller shaft, alone, is a serious one which for a time may fail of solution, and may defer the realization of this speed for many years. There are hundreds of problems that the engineer and the naval architect must attack and solve before success can be attained. It may, however, be considered as not at all improbable that those of us who live to the next century may see the Atlantic crossed in less than four days.

## THE ENDURANCE OF STEEL RAILS.

From "Iron."

As a great many questions have been asked me as to the comparative durability of iron and steel rails, I have thought that the nineteen years' results on the London and North-Western line of railway, which I have been able to

tabulate, might be of interest to the members of the Iron and Steel Institute, and I beg to submit a diagram to this meeting showing the comparative numbers of tons of iron and steel rails used for relaying purposes on the railway in question, from 1867 to the end of this year, the last year being, of course, the estimated requirements. On the same diagram I have shown the quantity of coal burned yearly in the locomotives, as I take it that this is the only reliable way in which we can arrive at the amount of work done on the line in each year; and, as a check upon the coal consumption, I have also shown on the diagram a line representing the train miles along with the engine miles, and it will be seen at a glance that, while the coal line very closely follows in proportion to the train miles and the engine miles run in each year, the quantity of rails used for renewals has been a constantly decreasing amount since 1877. From 1868 to 1877, we were putting down both iron and steel rails on renewal account. I have shown the iron and steel rails separately in the diagram, and the combined iron and steel in a double line. It will be noticed that in 1868 the quantity of iron and steel rails required for renewals was, roundly, 16,400 tons, and that the largest weight of rails required for renewals was arrived at in 1876, twelve months after which iron rails entirely disappeared —the total number of tons used in that year (1876) being 31,391, while the estimated requirements for this year are only 11,600 tons.

Practically, the whole of our main lines are relaid with steel; and while, in past years, we have been putting down steel rails as fast as iron ones wore out, we are now putting down steel rails as fast as steel rails wear out, except on some of our branches, where iron rails, of course, last a much longer time than on the main line. From what I can see, by watching closely our own line, I believe we have now reached the minimum required for renewals, and that our renewals will rather increase than otherwise, but at a much less rapid ratio than they did up to 1876. The small quantity of rails required for renewals on the London and North-Western Railway, if other companies have re-laid their roads with steel at anything like the same rate, will account in some measure for the depression in the steel rail trade; and, as our steel rails wear out, the quantity of pig-iron required to keep the road going will be represented as nearly as may be by the difference in weight between the rails when put down and when taken up for renewal, plus 7½ per cent. for loss in manufacture. This will also represent very closely the quantity of iron required for the bath in the Siemens furnace for remelting the old steel rails, so that for a considerable period the quantity of iron required on such a line as ours will be much less than it has been during the past period; but, if steel sleepers are found to answer—and I see no reason why they should not—I hope they will, in a great measure fill up the want of orders for steel rails in our various large works.

On our main line, up to the present time, we have put down 45,000 steel sleepers; and, on recently examining those we first put down on the Chester and Holyhead line six years ago, I found that they were in very good order, with no signs of loose rivets, though these sleepers were made with a much less chair base and leverage for the rivets than those we are making now. While on the subject of steel sleepers, I may observe that there has been a good deal of discussion and a number of questions have been asked me as to their tendency to work endwise, especially in curves; but, so far as our experience goes, when properly ballasted up, we do not find this tendency. Our engineer, Mr. Bradford, who has had some of these sleepers down for a considerable time in our South Wales districts on gradients of 1 in 38 and on a curve of 10 chains radius reversing into one of 15 chains radius, finds no tendency to working endwise; and, while going over the road previously referred to in North Wales with some Scottish engineers, I pointed out to them in many cases moss was growing on the end of the sleeper, and on the ballast, without the slightest sign of disturbance. As it may interest the members of the Iron and Steel Institute to see the present form of the steel sleeper and chair, I have ventured to send one for inspection at the meeting.

# OBITUARY.

# DAVID VAN NOSTRAND.

DIED JUNE 14th, 1886.

The sad duty of announcing the death of the founder and publisher of this Magazine devolves upon us in the preparation of the present issue.

The grief that is born of the breaking of the bonds of a long friendship is but poorly assuaged by the enumeration in type of the virtues that, year by year, made that tie stronger.

Only those who shared the friendship and fully knew the qualities of this truly Christian gentlemen can share the sorrow now. What he was to a large circle of friends is only too keenly felt to require any attempt to express its measure. What he has been to society and the world is a matter of completed history, in which a larger circle of acquaintances will find a sad interest.

David Van Nostrand was born in New York City, in December, 1811. At the age of fifteen he entered the service of John P. Haven, then a bookseller on Broadway, at the corner of John Street. The engagement with Mr. Haven continued till 1834 (eight years), when Mr. Van Nostrand became associated with Mr. William R. Dwight, and established the firm of Van Nostrand & Dwight. The trade of this firm was chiefly in religious books; it continued for three years, the copartnership being dissolved in 1837. During the next ten or twelve years Mr. Van Nostrand devoted much of his time to the study of scientific subjects, giving special attention to works on civil and military engineering. He became an accountant in the employ of Gen. J. G. Barnard, who was then directing the construction of the fortifications near New Orleans. The experiences and associations of his life at New Orleans determined the direction of Mr. Van Nostrand's later efforts. The acquaintance formed with military engineers, the interest he had cultivated in the subjects that engaged their attention, together with an aptitude for business acquired in his previous experience, all prompted him to begin a trade in scientific books. He began by importing foreign books for the officers of the Army. The business soon assumed unexpectedly large proportions. Importations through his hands were made for various institutions, including the Military Academy at West Point.

In 1850 Mr. Van Nostrand was again established in the book trade in New York. The store at the corner of John Street and Broadway was for nearly twenty years a favorite resort of military men, as well as of students of all departments of science. In a brief historical sketch published in the *Evening Post* in 1875, the following account is given of Mr. Van Nostrand's enterprise:

"At that time (1850) the publication of scientific works as a specialty had not been attempted in this country, although various houses had published fugitive volumes of some value. Encouraged by his growing trade of importation and sale, Mr. Van Nostrand soon ventured to enter upon publishing ventures. In a few years, by persistent and conscientious labor, he built up a business which it is not too strong language to say commanded the admiration of the scientific world, and *Trübner's Literary Record*, of London, while remarking that the United States, although 'prolific in practical applications of science, had been, through obvious causes, somewhat sterile, until a quite recent date, of literary expositions of its works,' admitted that of late years there had been 'a great and rapid development of such works, and with no name is this development more intimately associated than that of Mr. Van Nostrand.' Again this English journal remarked that 'as a gentleman of extensive and varied information, of genial and attractive character, eminent business capacity, and of important achievements in his profession, Mr. Van Nostrand stands prominent among the publishers of the day.' And it well may be added that very few men are so constituted as to be able to wait patiently for the growth of a great business in a field which promises no reward except as the fruits of many long years of toil."

The demand during the Civil War for works relating to military tactics and military engineering naturally stimulated the trade already firmly established at this well-known center. Writers on subjects relating to military science came there to find a publisher, and as Mr. Van Nostrand's scientific knowledge and rare natural power of discrimination were brought to bear upon the offered treatises, it followed that the works published by him became standard authorities, and are now well known everywhere.

The growth of the business at length required more spacious quarters, and in 1869 it was transferred to the present location, in Murray Street. Since the removal the publication of works relating to civil engineering has been an important part of the business, and in this field also Mr. Van Nostrand was foremost in the production of works which soon became standard reference books. During the last two years Mr. Van Nostrand has been an invalid, although not entirely incapacitated for business until the beginning of the present year. Since the 15th of January last he has only been seen by his more intimate friends.

Throughout his busy career Mr. Van Nostrand enjoyed the reputation of possessing rare social qualities. He was a prominent member of both the Union League and the Century Clubs, and in both he was called upon at times to take an active part. He was twice married. His second wife survives him.

The affectionate regard which his sterling qualities had won from a wide circle of his fellow-men, causes deep sorrow for his loss, and will ensure his lasting remembrance.

## REPORTS OF ENGINEERING SOCIETIES.

ENGINEERS' CLUB OF PHILADELPHIA.—*Record of Regular Meeting, April 15th*, 1886.

Mr. E. S. Hutchinson read a paper giving a résumé of the Report of the Hon. John Bigelow on the Panama Canal made to the New York Chamber of Commerce.

After stating that the Chambers of Commerce of some European cities as well as that of New York were invited by Mr. De Lesseps to send delegates to assist at the inspection of the Canal in February last, he briefly described the work as follows:

The project contemplates the construction of an open ship-canal, without locks, from Colon, on the Atlantic side of the Isthmus, up the Valley of the Rio Chagres, through the Cordilleras at Culebra, and down the valley of the Rio Grande to the bay near Panama, on the Pacific. Beginning at sea-level at Colon, the canal reaches Matachin, 27 miles, with cuttings varying from 20 to 168 feet; from Matachin to Culebra, 7 miles, the hills are from 100 to 240 feet, while at the latter point the crossing of the Cordilleras, the maximum cut is 320 feet; along the 8 miles to sea-level the decline is rapid. The four miles remaining will be dredged 325 feet wide in Panama Bay to Perico Island. The plan necessarily includes the erection of a breakwater and other extensive harbor improvements at Colon, with a breakwater and jetties, and a tidal-basin at La Boca. Depth of water to be maintained, 27 to 29 feet. In the low lands the widths will be 164 and 72 feet, top and bottom respectively; and in the Cordilleras they will be 102 and 78 feet.

The original plan "Mr. Hutchinson believes" contemplated the construction of "sidings" or passing places every six miles; but the Report mentions only one, 3 miles long, at Tavernilla, 19 miles from Colon.

The most serious obstacles to be overcome are treated of under four heads:

*First.*—The control of the River Chagres.

*Second.*—The cut through the Cordilleras at Culebra.

*Third.*—Keeping the channel open from mouth of the canal at La Boca to near Perico Island.

*Fourth.*—Securing the labor required at practicable rates.

The Report states that the Chagres, which, with its tributaries, has a normal flow of 450 to 500 cubic feet per second, has recently been known to rise 40 to 50 feet, and discharge 2,550 cubic yards per second; and in 1857 Col. Totten gauged it at 2,093 cubic yards per second; and that the improved channel of the Chagres will carry off 520 cubic yards per second, so that, at a time of maximum flood, 1,573 cubic yards per second will have to be provided for. He mentioned the two plans that have been proposed to get rid of the dangerous surplus; one, the construction of lateral channels, and the other the building of a catch-water basin, large enough to hold a flood or two of the Chagres. Mr. Hutchinson said that within a few days he had been officially advised that both plans are still under consideration by the Technical Commission, though Mr. Bigelow is of the opinion that the "dam" project is most in favor.

He condensed from the Report a description of the "dam;" three-quarters of a mile long, 140 feet high, 1,300 feet wide at base, with exterior slope of 4 to 1. Waste-weir, a 20-feet diameter tunnel, with in-dam orifice 80 to 100 feet *above* bottom of dam. Quantity of material, 9,000,000 cubic yards, with a reservoir capacity of 4,000,000,000 cubic yards. He pointed out the important omission from the Report of the results of the examinations for depth of foundation for the dam, and also of estimate of cost of cost of construction.

He quoted from the Report that the maximum cut at Culebra was 320 feet, and that quantity of material to be removed at this point, and within 1½ miles, was 26,000,000 cubic yards. The Report goes on to state that the Anglo-Dutch Company, which had contracted to remove 915,000 cubic yards per month, has never excavated 131,000 cubic yards per month, that only 1,250,000 cubic yards had been removed up to January 1st, 1886, and that this contract was so modified that from 800,000 to 432,000 cubic yards per month were to be taken out during the next three years, ensuring the completion of the work by July 1st, 1889.

Mr. Hutchinson concluded that from the meagre figures given this would be impossible, and that, if there were no increase in the rate, fifteen years will be required, even if no serious or unforeseen delays occur. He noted the important fact that the Company was to furnish machines and men, and that, having failed in its part of the contract, the contractors were released from all obligations.

He was of opinion that the Report did not show that careful surveys had been made of the Panama terminus, as important questions mentioned elsewhere were not touched upon. "Plans," it states, "are in contemplation for a dam across the Grande, for a dyke 4 miles long, from Gama Point to Naos." No mention is made of the tidal-basin, ¾-mile square, which is deemed indispensable, and has recently been estimated will cost $30,000,000. It went on to state that very little work has been done at this terminus, none within the shore line, and that very extensive repair and construction shops had been erected near the Mangrove Swamps, and that the pestilential exhalations were particularly fatal to skilled labor.

He noted that the Report treated the labor question quite fully. It points out that the native supply was very limited and uncertain, and that agents of the Company were constantly employed in all of the available markets gathering recruits; that the percentage of desertions was heavy; that of the 12,000 men on the rolls, the number is thought to be considerably exaggerated; that unskilled labor, which at the beginning had been 90 cents, was now $1.75 per day; that skilled black-labor ranged from $2.00 to 2.75 per day, while white mechanics received $5.00 gold.

He drew attention to that portion of the Report which states that the American Contracting and Dredging Co. had a contract for excavating 39,250,000 cubic yards of dredgible material from the Port of Colon, from the Main

Canal, and from the Auxiliary Canals, for th improvement of the Rio Chagres, and extending from Colon to Matachin, about 27½ miles. There will be 18⅝ miles of auxiliary canal. Work was begun early in 1884 and has been kept up steadily, there being at present 7 dredges at work. Up to January 31st of the present year this Company had excavated about 7,000,000 cubic yards, the amount for January being 952,000 cubic yards. Mr. Bigelow appears to have no doubt but that this Company will have its work completed by the stipulated time, December 1st, 1877.

Mr. Hutchinson also observed that a list is given of *six* contractors who were to have had contracts amounting to $125,000,000, only one of which, the American Contracting and Dredging Co., is mentioned as having done any work, unless it be that the Anglo-Dutch Co., which is reported as at work on the Culebra cut, is identical with the "Societé de Travaux Publique et Construction Companie," which he is unable to determine.

He considered it desirable to know whether or not any of these companies have thrown up these contracts? What companies are still at work? Where on the line they are located? What amount of work has been done by each?

He quoted from the Report that on January 31st there were 21 dredges and 82 excavators on the work, "with the auxiliary boats, trains and machinery," and added that for further details we must seek elsewhere.

He abstracted the quantities as follows: The total excavation necessary to complete the work was given by the engineers at 157,000,000 cubic yards. To February 1st, 1886, there have been done 18,500,000—11¾ per cent.—leaving 138,500,000 yet to be done—88¼ per cent.

| | Million cubic yards. |
|---|---|
| Total excavation, Jan. 1st, 1886... | 17 |
| Total excavation, Sept. 1st, 1884 .. | 10 |
| Total excavation, 16 months..... | 7 |

Average per month for 16 months, 425,000 cubic yards.
The work for January, 1886, was 1,400,000 cubic yards.

He remarked that at the latter rate about eight years from February 1st, of this year, would be required to complete the work, were there no other problems than that of excavation to be considered, and that the unknown quantities in the problem were too many for ordinary methods of solution.

Mr. Hutchinson pointed out that, as regards the matter of expenditures Mr. Bigelow adds nothing to M. De Lesseps report of July, 1885; nor is the date of closing of the financial year given. Adopting the figures of this report we have total amount realized to that date: 94¼ million dollars; expenditures, 73½ millions; balance, 20¾ millions dollars. Of the total expenses only 23 million dollars—31 per cent.—were for installing machinery, clearing line and excavation; the remainder were for expenses of organization, supplies and plant. Since that date the company has received 25 million dollars, but what the expenses have been approximately for the past year, more or less, Mr. Bigelow does not inform us.

The paper concluded by remarking that the map accompanying the Chamber of Commerce report was on the small scale of about 46 miles to the foot, and that it appeared to be a copy of one made to show the condition of the work June 1st, 1884—two years ago.

The final conclusion seemed to be that in the interest of engineering it was to be greatly regretted that the inspection and report had not been made by a thoroughly equipped engineer.

Dr. R. P. Robins, introduced by Mr. T. M. Cleemann, read an interesting account of the First Permanent Tramway in America, which was projected by Mr. Thomas Leiper, of Delaware County, Pa., in 1809, for the transportation of stone.

After experimenting in the yard of the Old Bulls Head Tavern, Second street above Popular Lane, Philadelphia, as to the feasability of such a roadway, he advertised in the *Aurora* of September 28th, 1809, as follows: "I wish to contract for the digging part of a railway, from my quarries on Crum Creek to my landing on Ridley; the distance and level has been accurately ascertained by Mr. Reading Howell. The distance is exactly three-fourths of a mile, and an accurate statement of the quantity of digging required may be seen from the plot in my possession, calculated by Mr. Howell. I also wish to contract for the making and laying the rail part of the same, consisting of wood, a specimen of which, as furnished by Messrs. Large and Winpenny, may be seen by applying to them at their manufactory, adjoining the Bull's Head in Second street, in the Northern Liberties. The scantling for the above will be furnished on the ground. I wish to progress in this work immediately."

The work of building and grading was immediately begun, the draft of the road being made by John Thomson, and the railway was finished early in 1810. "The ascents were graded inclined planes, and the superstructure was made of white oak with cross-ties and string-pieces. The cars or trucks were very similar to those now in use, the wheels being made of cast-iron with flanges." "The road continued in active use until 1828, when it was superseded by a canal after the plan made by Mr. Leiper, but not carried into effect until three years after his death, when his son, the Hon. George Gray Leiper, concluded the work which had always been nearest to his father's heart." The site of the old road can still be seen, though it is in ruins, nothing remaining excepting the deep cuts made by the cross-ties. There has been a great deal of discussion of late years with regard to the claim of priority for this road, it having been claimed by various New England writers that an earlier tramway had been built in or near Boston. But as nearly as I can arrive at any conclusion upon the subject, the only road constructed before the building of Mr. Leiper's tramway in Delaware County, was that on the western slope of Beacon Hill, which was designed and executed by Silas Whitney in 1807, and which was about a quarter of a mile in length. "It was used for the transporting of gravel from the top of the

hill down to Charles street, which was being filled up and graded. There were two trains of cars on the railway, so arranged that one train being loaded with gravel would in its descent pull up the empty train. While the full cars were being emptied, the unloaded cars were being filled, and in their descent would haul up the first train, thus doing the work without horses." This road was, however, only temporary, and as the work of grading progressed was gradually removed. It is, however, entitled to a mention as the first work of the kind in America, having been put into active operation at least two years before Mr. Leiper's preliminary and experimental railway in the yard of the Bull's Head Tavern. Mr. Leiper's road in Delaware County was, however, the first permanent tramway constructed in this country; the next in point of date "was that laid in Nashua, N. H., in 1825; the third, was the one laid down at Quincy Granite Quarries, in Massachusetts, in 1826-27; and the fourth, the Great Enterprise at Mauch Chunk, Pennsylvania, nine miles in length, to which the former ones are mere child's play."

Dr. Robins' description contains full quotations from various historical authorities, contemporaneous newspapers, etc. A vote of thanks was extended to Dr. Robins for his very entertaining contribution.

Professor L. M. Haupt exhibited an original drawing of Josiah White's, containing designs for Dams No. 3 and 4 on the Lehigh. They were built of round timbers, filled with rip-rap, and were each about 36 feet high. Mr. White is known as the inventor of the earliest form of movable dam, known as the "Bear Trap," which he built at the mouth of the Lehigh, at Easton, in 1818.

Professor Haupt also presented some extracts from a paper on the Philadelphia Traction Co's Lines by Mr. H. R. Stoops, wherein a comparison is made between the cable and horse systems of street railways, favorable to the latter. Remarks were made by Mr. Henry G. Morris on an Electric Motor Car, and by Mr. John T. Boyd on Traction Cables and Machinery.

## ENGINEERING NOTES.

A very interesting paper on the irrigation of the oages of Merv and Akhal-Tekke was recently read by M. Pokrovski-Kozel at St. Petersburg, before the Society for the Assistance of Russian Trade and Commerce, Count Ignatieff being in the chair. The lecturer considers the Merv oasis as one of the most fertile spots on the earth. Wheat, rice, and other cereals cultivated by natives for home consumption, yield beautiful crops. The oasis includes about 900,000 acres of cultivable land. But in order to cultivate them it would be necessary to colonise the oasis with civilized pioneers, and to spend about £120,000 on the restoration and extension of the splendid system of canals built up by the Arabs a thousand years ago, and preserved until now in some parts—as, for instance, at the mouth of the river Murhab, about fifty miles from Merv. These canals are 14 ft. deep and 70 ft. wide, and partly used even now by the Merv Turcomans for the irrigation of their fields, though in a primitive manner. The Akhal-Tekke oasis is not so rich as that of Merv, but still it has about 900.000 acres of land suitable for culture. It covers the space of seven miles along the railway line from Mikhailovsk Bay to Khizil Arvat, and could be irrigated by the water from the river Tejen.

Consequent on a survey of the main sewer under the Palace of Westminster, an interim report of the committee on the subject has been presented by Sir Henry Roscoe. "The committee are convinced that the air of the Palace of Westminster is subject to contamination by sewer gas emanating from the low level sewer of the main drainage of the metropolis with which the system of drainage of the palace is in direct connection. Undoubted evidence has been obtained that sewer gas from this source passes into the drainage system of the palace in times of flood, and under the circumstances, owing to the absence of proper ventilation in the low level sewer above referred to and to other causes, the committee are convinced that a complete reconstruction of the main drain under the Houses of Parliament and an entire alteration of the means of discharging the sewage from the palace into the main low level sewer are urgently required for the safety of the members of the Legislature and of the officers residing within the precincts of the palace. The committee therefore beg to recommend to the House that the Board of Works be instructed at once to carry out certain remedial measures which the committee are now prepared to suggest, and which in their opinion will effect the desired result."

A meeting of the Committee of the National Smoke Abatement Institution was held at the Parkes Museum on the 6th inst., Mr. Ernest Hart in the chair. A letter was read from the Home Secretary saying that from correspondence with the commissioners he is satisfied that the police have taken proceedings in all cases of smoke nuisance in which they could properly do so, and exercise due supervision over the steamers on the river, adding that the extension of the area to which the Smoke Nuisance Acts apply is a matter for the consideration of the Legislature. A sub-committee was appointed to correspond further with the Home Secretary, and to urge upon the Government the necessity for the extension of the area embraced by the acts. The secretary reported that the furnace of a steam launch on the Thames at Hampton had been tested by the engineer of the Institution, who in his report stated that during a run of thirteen miles no smoke was visible at the top of the chimney throughout the trip, an improvement of great importance to all owners of launches. Several descriptions of new appliances for smoke abatement were reported and discussed, and it was resolved to publish shortly a selection of the numerous tests of apparatus made by the Institution since the publication of the report on the Smoke Abatement Exhibition in 1881-2.

COMMENTING on the proposals of the Metropolitan Board for dealing with the metropolitan sewage, the London *Lancet* says: "As to the disposal of the effluent, we quite agree that it must be disinfected somehow before it goes into the river. At present the sewage must be treated at the existing outfalls, for the danger of the present system is urgent, and some chemical disinfectant must, therefore, be used. Whether permanganic acid is the best we cannot say; possibly it is. But, although it is inapplicable at Barking and Crossness, land irrigation is a better means of purifying sewage effluent than any chemical disinfection; and, when the sewage goes down to Sea Reach, as we trust it will before many years are past, the final purification will probably be done by the soil, and an almost perfectly pure effluent thrown into the river. The committee are, indeed, so enamored of their permanganate disinfection that they have quite given up the idea of moving from their present outfalls. They say, on the authority of the chemists who advise them, that 'the necessity for land filtration no longer exists, and thus the great objection to the treatment of the sewage and the discharge of the effluent at the present outfalls is overcome. To this we most strongly demur. We are more than ever convinced that the sewage of all London ought not, even after chemical treatment, to be thrown into the river at Barking and Crossness; and we decline to receive on this point the assurance of certainty from chemists who, three years ago, were equally sure that no important injury was done to the river by the raw sewage. We are sorry that the Board persists in this obstinate resistance to the recommendations of the Royal Commission. They have been forced into their present action, after a hard fight, by the pressure of scientific and public opinion, and now, instead of giving in gracefully and obeying the wish of the nation, they contest every inch of ground in their retreat."

STRUCTURES ON COMPRESSIBLE FOUNDATIONS.—The subsoil at Chicago, U. S., is wet clay, and yielding to an extent which has caused serious difficulties on many of the heavier buildings by the unequal settlement. One of the most prominent examples is that of the United States Government building, which was built upon a bed of concrete 3 ft. in thickness; the inequality of the pressure upon the foundations has caused an uneven subsidence and many undesirable consequences have taken place. The concrete foundation has become broken, and cracks in various portions of the masonry, even to distortion of arches, and in two instances stones are reported to have dropped from the decorative work (on April 21) to the jeopardy of persons on the sidewalks around the building. As an example of what can be accomplished by the exercise of engineering skill under similar limiting conditions, the Home Insurance Company's Building, in the same city, is a fire-proof structure of great weight, being 160 ft. in height, and constructed of masonry and iron. The foundation consists of independent piers built of alternate courses of dimension stone and rubble, and the area of the bottom carefully proportioned to a surface of a square foot to each two tons of load to be supported by the pier. In this manner each basement pier and each vertical line of columns rested upon an independent foundation which was loaded to a uniform intensity per square foot. The beams and girders were very securely anchored together at walls and at intersections, and strips of band iron built into the masonry over arches and other places where reinforcement might be desirable. The whole building has subsided $2\frac{1}{4}$ in., but owing to the care in placing loads of uniform intensity of stress upon the foundation, the maximum inequality in settlement has been only $\frac{1}{16}$ in. In our day and generation the wise men are not limited to those who build their house upon a rock, but must include those who make the sand as stable in its resistance as a rock. The original peninsula comprising the city of Boston, U. S., has been distorted into some other geographical form, and more than doubled in area by the filling over the harbor and estuaries by about 16 ft. of gravel over clay and mud forming the bottom. The large buildings constructed upon this "made land" have received the benefit of skilled engineers in regard to the distribution of the loads upon the piling which support the stone foundations, and bid fair to remain permanent without any distortion, but many of the elegant private residences on the Back Bay district of the city, being erected under the sole direction of architects who did not avail themselves of the work of engineers familiar with that special branch, have settled irregularly, and many fine buildings are marred by cracks in walls and ceilings. This criticism does not apply in so great a measure to many of the later buildings where more judicious measures have been introduced to provide for uniform settling. The architects are not alone at fault here, for the abutment piers of a highway bridge over a railway on this district were moved laterally, foundations and all, some twelve years ago by the earth pressure caused by the approaches.

## IRON AND STEEL NOTES.

A PAPER was read at the last meeting of the Chemical Society, on "The Influence of Silicon on the Properties of Cast Iron," Part III., by Mr. Thomas Turner. The paper considered in detail the Woolwich Report, "Cast Iron Experiments, 1858." This report included the chemical analyses and mechanical tests of seventy specimens of British cast iron. The author classifies these irons according to the amount of phosphorus present. Some of the more important results are as follows:—(1) Only eight specimens were mentioned as being "too hard to turn;" seven of these contained under 0.9 per cent. of silicon, while the eighth was rich in phosphorus and sulphur, facts strongly supporting the author's conclusion that a softening effect is produced by a suitable proportion of silicon. (2) The six best specimens mentioned in the report contained on an average 1.393 per cent. of silicon, while the author, from his own experiments, recommended

about 1.4 per cent. These and other results support the view that a suitable proportion of silicon is beneficial. (3) When the specimens are classified according to their proportion of phosphorus and arranged in tables in order of silicon present, a gradual improvement is noticed as the silicon increases until a certain point is reached, beyond which point the metal deteriorates in quality. In the discussion on the paper, Professor Unwin noticed the popular prejudice that silicon is a very injurious constituent of cast iron. This prejudice arose a long time ago, apparently from the difficulty experienced in smelting very rich iron ores containing much silica. Thus, the Turkish Government, in 1884, wished to utilize an exceedingly rich ore—magnetic ore containing 12 per cent. of silica—found at Samakoff, but could not smelt it, and the difficulty was attributed to the silica. Again, about 1853, attempts were made to improve cast iron guns, and Mr. Cochrane advised the use of Nova Scotia iron. This was tried at Woolwich, but the Chemical Department there refused to sanction its use on the ground that it contained too much silicon, notwithstanding that Fairbairn's mechanical tests were in its favor.

New Iron Enterprise in South Russia.—We learn from St. Petersburg that a company has been formed, with a capital of two millions sterling, to work the iron deposits of the Krivoy Rog district, reputed to be the richest in the world. Situated in the Ekaterinoslaff Government, they first became thoroughly known after a systematic survey conducted by the Russian authorities a few years ago. The Ekaterinen Railway was then constructed by the Government to connect the deposits with the coal-fields of the Donetz valley, and since the completion of the line, in 1883, upwards of 3,000 tons of ore have been sent regularly every month to the works of Hughesovka alone, the price, including placing on the railway truck, being 2½ copeckes a pood, or 2s. 8d. the ton. Last year a fresh outlet was opened in Poland, a quantity being sent from Krivoy Rog to several of the iron and steel works in the Vistula region. Yielding 68 per cent. of splendid metal, the ore gave such satisfaction that an international company, favored by the Russian Government, was formed to develop the mines on a large scale. The capital subscribed was 19,500,000 roubles, of which the Warsaw Steel Works have furnished 2,500,000 roubles, Lilpop & Rau 1,500,000 roubles, and the remaining 15,500,000 roubles has been made up by foreign capitalists, including Cockerill & Co., the Grande Société Franco-Italienne des Houilles et Foches à Paris, the Reinische Stahlwerke of Ruhrort, the banker, Surmont, of Aix-la-Chapelle, and Messrs. Ransome & Co , of London. As an encouragement the Russian Government has agreed to give the company an order for 70,000 tons of rails, 30,000 tons of railway material, &c., amounting in value to over a million sterling, of which a considerable amount will be paid by the Government in advance A clause in the agreement also provides for a bounty on steel rails manufactured on the spot. For some time past agents of the syndicate have been completing the arrangements at Ekaterinoslaff for starting the concern, and it is believed that it will be placed on a good working footing by the winter. Another scheme, favored by Krupp, for establishing a gun foundry for the Russian Government in the Krivoy Rog district, has also been discussed during the spring; but the terms asked by the German syndicate were not favorable enough to please the Minister of War. The project, however, has not yet entirely fallen through, and even should no foreign capitalists embark upon the enterprise, it is believed that the Ministry of War itself will establish an arsenal there for supplying weapons for the use of the Black Sea fleet. At present the guns mounted on the coast batteries and men-of-war of the Euxine are manufactured in the Ural Mountains or at St. Petersburg, and the cost of the conveyance over many hundred miles of railway is very heavy. The saving effected by establishing an arsenal in the Krivoy Rog district would thus justify a considerable subsidy.

The corrosion of steel is a matter of greater importance than some of our experts imagine. It is not only during the first six months that the paint falls off the bottom of steel vessels. I was informed the other day by the principal of a well-known Tyneside anti-fouling paint company, who manufacture both Rahjtens and the International paint, that he has found steel vessels, when even two or three years old, to be almost "bare" when docked; whereas, iron vessels under the same circumstances have still a good "body" of paint left. It is his opinion when two coats of paint are sufficient for an iron vessel, three coats are required for a "steel" one. The fact is "Lloyd's" surveyors cannot see the "mill-scale" properly removed by the painting of the vessel being postponed as long as possible in the case of a vessel being contracted to be delivered in six months—not an unusual occurrence. In a few months the mere action of the atmosphere does little to remove the outer skin of steel, so closely is it combined with the main body of the material. I think in all cases the Government practice of dipping the plates and bars in diluted hydrochloric acid and scrubbing them with steel brushes should be insisted upon.

Changes in Iron due to Magnetization.—Mr. Shelford Bidwell has been making further experiments on the changes produced by magnetization in the length of iron wires under tension. His results, as recently communicated to the Royal Society, disclose the following facts. An iron wire under tension and subjected to a gradually increasing magnetizing force, is at first elongated, unless the load be great, then it returns to its original length, and finally it contracts. The maximum elongation diminishes as the load increases, according to a law which seems to vary with different qualities of iron. If the ratio of the weight to the sectional area of the wire exceeds a certain limit, the maximum elongation, if any, is so small that the instrument fails to detect it. The retractation due to a given magnetizing force is greater with heavy than with light loads. Both maximum elongation and

neutrality (*i. e.* absence of elongation and retraction) occur with smaller magnetizing currents when the load is heavy than when it is light; retraction, therefore begins at an earlier stage. The phenomena, both of retraction and elongation, are as might have been expected, greater for thin than for thick wires, and for soft than for hard iron.

## RAILWAY NOTES.

THE KOLOMNA WORKS.—According to a recently published report, the Kolomna Works in Middle Russia, which are under the control of General Struvé, the eminent bridge builder, have constructed during the last two years upwards of 140 locomotives for the various Russian railways. A few weeks ago the Minister of Ways of Communication, General Possiet, invited tenders for building sixty more. On examining the applications, 27 were assigned to the Nevsky Iron Works at St. Petersburg, belonging to the Russian Mechanical Society; the price arranged per each six-wheel locomotive, of 32 tons, being £75 a ton, or £2,400 apiece. For several years the Nevsky Works have received no Government orders, and hence put in a low tender. The Kolomna Works wanted 800 roubles a ton, or £2,516 apiece for the remaining 33 locomotives, and refused to make them at the same price as the rival St. Petersburg firm; in consequence of which their application was refused. As, however, the Government wants the whole of the 60 with as little delay as possible, and the Nevsky Works cannot do them all in the appointed time, it is believed that the deadlock will result in the Kolomna Works securing its proposed terms. Of late a large number of locomotives have been withdrawn from the Government reserve (several hundred being kept on hand in readiness for any war), in order to equip the Transcaucasian and Transcaspian railways, and the Minister of War is anxious that the complement should be made up afresh this year. We called attention the other day to the fact that the Russian Government, which has been lagging railway construction for several years, has gone ahead again this year, and the additional demand for locomotives this will occasion has led to several firms in Russia expressing their intention of manufacturing them. It will some time, however, before they will seriously compete with the Kolomna and Nevsky establishments.—*Engineering.*

A REMARKABLE instance of the effect of competition by sea and land which at present exists has been brought to our notice within the last few days. The *Railway News* says a contract has just been entered into between the agents of Italian railways for the delivery at Venice of coal shipped at Cardiff and Swansea, free of all charges, at 20s. per ton. This is exactly the price at which the same coal is delivered to the Metropolitan Railway Company in London, the competition between sea-going ships being so severe that the freight is little more than nominal. Another illustration of the effect of competition by sea with our own railways is afforded by the fact that the quantity of coal brought by coasting vessels into London from Welsh ports has increased to such an extent as seriously to curtail the quantity carried by the Great Western to London. For the two months of the current year the decrease in coal carried to London on the Great Western was over 20,000 tons as compared with 1884. There is sea competition also with other ports as well as with London. At the meeting of the Great Western Company Sir Daniel Gooch stated that coal was conveyed from Cardiff to London at 4s per ton, or equal to a railway fare of one farthing per ton per mile—a rate with which the railway companies could not profitably compete.

THE third main division of the report on the railway accidents in the United Kingdom in 1885 deals with accidents to servants, whether of companies or contractors, caused by the traveling of trains or other vehicles on railways. Here we find 438 killed, and 2,036 injured, while the causes of injury are too numerous to be mentioned in detail. The most fatal risk to which the servants are subjected is working on the permanent way, sidings, &c., whereby 107 were killed and 123 injured; while walking, crossing, or standing on the line on duty caused 79 deaths and 108 injuries. Altogether, what with passengers, others of the public, and servants, the total number of persons killed during the year 1885 was 957, against 1,134 of the year before, and of injured 3,467 persons, against 4,100 in 1884. It is satisfactory to note that not only the totals but almost all the items have materially decreased from the year before.

## ORDNANCE AND NAVAL.

THE Russian Government are going to test exhaustively the watertight compartments of all their new vessels. They began the other day with a corvette cruiser which was finished last autumn; and although ample notice had been given, so that any little defects might be set right, when the compartments were filled the water gushed out from many places which had been overlooked. Finally, after a great deal of door-adjusting and leak-stopping, the large compartments were proved to be watertight in fact as well as in name. The Russian Admiralty authorities seem determined to take nothing for granted—an example which some other Admiralty authorities nearer home would do well to follow.

AT this year's meetings of the Institution of Naval Architects a somewhat insignificant incident formed a notable feature of the first day's proceedings. A paper had been read descriptive of an instrument invented for the purpose of indicating the strains to which ships are subject at sea, and in the discussion thereupon, Mr. Ramage, a Scotch shipbuilder, bluntly advanced the notion that such subjects were the business of Lloyd's Registry, and not not of shipbuilders; shipbuilders have to carry out Lloyd's rules, and all their energies are required to make shipbuilding pay. Scientific investigation under such circumstances is the business of the framers of the rules, and not

of those who have merely to work them. Shipbuilders present protested against this notion, but only adduced the case of light-draught steamers and other vessels built for exceptional work as affording scope for original design as regards structural strength.

Two steamers for the Caspian have recently been put out of hand by Messrs. Boolds, Shever & Co., of Sunderland. They are named respectively the Cebah and A. H. N. They are fitted to burn crude petroleum, which is carried in an athwartship tank a little less than two feet in length, and thus occupying one frame space and extending the whole breadth and depth of the vessel. This tank is at the fore-end of the boiler room, and beside it there are two fore and aft tanks, one on each side of the boiler-room. Both steamers are built of steel; the Cebah is of dimensions, length, 148 ft.; breadth, 27.1 ft.; depth, 12.2 ft.; gross tonnage, 473. The A. H. V., length, 140 ft.; breadth, 24 ft.; depth, 11.3 ft.; gross tonnage, 370. The steamers will burn coal on their passage out.

The Steel-Wire Gun.—The new experimental 9.2 inch steel-wire gun has just been tried at the Government proof butts, Woolwich Arsenal, with satisfactory results. The War Department have issued orders for the construction of several more guns of the same description. The Government pressure test for the gun was 65 tons to the square inch. The new weapon weighs 25 tons, and is 33 feet long. The steel wire is coiled around the inner tube at the breach, and nearly up to the trunnions, and consists of 78 layers. The wire is made in lengths of 2,400 yards. It is flat, and is put on by a specially designed machine at a pressure of about 40 tons to the square inch. The lengths are joined together by being brazed and riveted together over a length of 15 inches. After the wire has been put on, a steel jacket is shrunk on over it.

Armorplate Trials at Spezia.—Important armorplate trials have just taken place at Spezia. A large chilled-steel plate, manufactured by Gruson, of Buckau, Germany, the greatest thickness of which is 1.75 meter (5 ft. 9 in.), had been fixed in a rock near Castagna Bay, this position being the nearest approach to that it will occupy in the finished turret for wich it is intended. The Italian Government proposes to construct two such turrets for the protection of Spezia harbor. The plate weight 100 tons, and is one of seventeen plates which are to form the turret. Their total weights with the parapet armor, is 2,500 tons. The turrets are to be armed with two breachloaders, firing projectiles of 40 centimeters (15.6 inches) diameter. They are to be proof against guns of the heaviest calibers yet manufactured, with which at present only the Italian navy is armed, but which may be introduced any day in other navies. A 43-centimeter (16.77 inches) gun from the Italian ironclad Lepanto had been placed on the pontoon moored 130 meters from the target. The projectiles used were Krupp chilled steel shells, weighing 1,000 kilogrammes each, the charge of powder being 7½ cwts. of prismatic cocoa powder, of German manufacture, which gives to the projectile an inertia of 15,000 meter-tons. The greatest inertia hitherto attained at the previous Spezia trials had been 13,500 meter-tons, and was employed against steel and compound plates of English and French make. None of them withstood, it will be remembered, a single shot, being either penetrated or broken up. It was the general impression among those who witnessed the trials at Spezia that the Gruson plate would share the same fate, it being assumed that nothing could withstand the force employed. The result proved otherwise. The first shot only caused a slight indentation a few centimeters deep, besides some trifling cracks. The second and third shots were no more effective, and the plate could have stood some more pounding without showing any serious injury. But the officials present considered that the plate had successfully stood the maximum test required. The trials show that turrets protected by such massive armor and armed with powerful guns, are to hold out against any attack, and, by inference, to disable ships attacking them.

## BOOK NOTICES

Retaining Walls for Earth. By Malverd A. Howe, C.E. New York: John Wiley & Sons.

The author has employed the method of Prof. Weyrauch, amplifying and applying the original analysis for the benefit of practical engineers.

Readers who do not care to verify the analytical investigation may begin with "Recapitulation of Formulae," on the 46th page. Beyond this, applications to practical cases only claim the attention.

The whole is a neat and compact little treatise on an important engineering subject.

Through the Yellowstone Park on Horseback. By George W. Wingate. 16mo, pp. 250. O. Judd Company. Price $1.50.

In the book before us we have the account of a summer's trip made by General Wingate, with his wife and daughter. The party started from Bozeman, with saddle-horses, baggage and tents, and spent nearly a month in riding through Montana to the Yellowstone Park, and then back through Idaho and the Madison Basin—a distance of over four hundred and sixty miles accomplished on horseback.

Graphic descriptions of the wonders of the National Park, experiences at the cattle ranches and with the cowboys, and the various hunting expeditions, are all very interestingly told. A full account of the routes by which the park can be reached, the outfits required both for ladies and gentlemen, the expenses of the trip, an accurate description of the game, and suggestions as to the proper method of hunting it, are all detailed in separate chapters.

The book is admirably written and is filled with illustrations, and is destined to become the authority on travel through that section of the country.

PRACTICAL HYDRAULICS. By P. M. RANDALL. San Francisco: Dewey & Co.

The plan pursued by the author in the preparation of this little hand-book consists:

1st. In demonstrating concisely the principle or principles involved, yet in a manner sufficiently ample to be readily followed by the student, or by any practitioner desiring to refresh his memory or to assure himself of the correctness of the results.

2d. In expressing in words the simplest rule or rules corresponding to the formulae.

3d. In applying the rule or rules thus derived to practical examples, with full and clear explanations.

4th. In providing tables to meet the requirements of practice.

The formulas and tables apply to most of the problems relating to water in motion, whether through pipes, over weirs, in open channels, or through nozzles, and for the purposes of affording power, for mining, for supply, or for irrigation.

ABRIDGEMENT AND DIGEST OF U. S. PATENTS ON UNDERGROUND ELECTRICAL LINES. By JAMES W. SEE, C.E., etc., etc. Published by the author, Hamilton, Ohio.

This book will be a valuable aid to inventors or users of electrical subways.

Wires for electrical conduction for any purpose must eventually be placed below the surface of the ground, at least in our large cities. Whether any one form of conduit will fulfill the many required conditions is yet a question.

In the meantime inventors are busy in devising plans, and are continually adding to the already long list of patented devices for conveying electricity below the surface of the earth.

The claims of this book upon the attention of electrical companies and their engineers are:

1. The abridgement of each patent recites every exhibit of the patent, whether such exhibit be involved in drawing or specification. In this respect the abridgement differ radically from the very unsatisfactory extracts found in the abridgements of English patents.

2. The claims are given in full.

3. Full indexes are provided both chronological and alphabetical.

4. The digest is exhaustive, and thoroughly analytical, ommitting no details. It is thought that this is the first published example of a thoroughly analytical digest of a given class of patents, the digest accompanying the English abridgements being little more than general indexes.

5. The underground line business is assuming vast commercial and legal importance, and the present work becomes indispensable in connection with questions which will arise.

## MISCELLANEOUS.

AT the Royal Institution, on the 27th ult., Professor Dewar exhibited the method he employs for the production of solid oxygen. Last year he gave a lecture on liquid air, but although he and other experimenters had made liquid oxygen in small quantity, yet no one had succeeded in getting oxygen into the solid condition. The successful device employed at the Royal Institution depends upan allowing liquid oxygen to expand into a partial vacuum, when the enormous absorption of heat which accompanies the expansion results in the production of the solid substance. Oxygen in this condition resembles snow in appearance, and has a temperature about 200 deg. Centigrade—360 Fah. below the freezing point of water. It is suggested that a supply of this material will enable chemists to approach the absolute zero of temperature—461 Fah. and to investigate many interesting changes in the physical properties of bodies under the primordial condition of the temperature of space.

A CURIOUS phenomenon has been observed by M. Blondlot, and communicated to the French Academy of Sciences. A disc of platinum and a disc of copper, 0.03 metre in diameter, were fixed vertically in front of each other by help of two platinum stands. The discs were three or four millimetres apart, and both were placed inside a bell jar of porcelain, open below. The apparatus was then heated red-hot for three hours by means of a gas furnace, and although there was no electric current, it was found that the face of the platinum disc was blackened wilh a deposit containing copper and platinum. In short, the copper had crossed from the copper plate to the platinum one. Mr. Blondlot, by repeating the experiment in different gas, found that the nitrogen of the air was the agent in this transport of matter. The nitrogen combines with the copper, and lodges on the platinum, either incorporating itself with the latter or decomposing in contact with it under the influence of its high temperature.

BUNSEN observed the dissociation of steam and carbonic acid by employing small tubes filled with an explosive mixture of these gases, to which suitable pressure gauges were attached. On igniting the gaseous mixture explosion took place, and a high momentary pressure was produced within the tube; from the pressure developed Bunsen calculated the temperature at which the explosion took place, and found that it varied with the mixtures employed. He records the circumstance that only about one-third of the combustible gases took part in the explosion, from which circumstance he concluded that the temperature attained was the limit at which combustion occurred. To prove this, Bunsen allowed the gases sufficient time to cool, after which a second explosion was produced, and even a third explosion when time was allowed for the gases to cool down again. Bunsen's theory seems very plausible, besides which he obtains much higher temperatures for his limits of dissociation than other physicists, so that the figures at which he arrives might be accepted; these are for steam about 2400 deg. C., and for carbonic acid about 3000 deg. C. These temperatures are probably higher than are reached in the arts, as materials used in furnace building would not withstand such temperatures for any length of time; but Mr. F. Siemens calls attention to the

circumstance that if the influence of the inner surfaces of the tubes on the combustion of the gases therein could be removed, the dissociation temperatures arrived at would be found still higher. He thinks that Bunsen's explanation of the cause of the second and third explosions is not quite satisfactory, as it is not the cooling of the gases alone which renders subsequent explosions possible, but also the thorough re-mixture of the gases by diffusion after each explosion.

THE CORROSION OF BOILERS.—MM. Klein and A. Berg have been studying the action of sugars on the corrosion of boilers, and find that sugar in water has an acid reaction on iron, which dissolves it, with a disengagement of hydrogen. The quantity of iron dissolved increases with the proportion of sugar in the water. The salt of iron formed is the acetate. A neutral decoction of malt also corrodes iron with disengagement of hydrogen; but glycerine and mannite are without action on the metal. These results are worthy of note in sugar refineries and places where sugar sometimes finds its way into the boilers by means of the water supplied. The experimenters in question also find that zinc is strongly attacked by sugar; copper, tin, lead, and aluminium are not attacked.

DAMASCENING BY ELECTROLYSIS.—A method of damascening metals by electrolysis has been brought out in France. Two copper plates are put into a bath of sulphate of copper solution, one being connected with the positive pole and the other with the negative pole of a battery. A thin layer of insulating varnish or wax is spread over one of the copper plates, viz., that connected to the positive pole, and the damascened device is etched on it. Now, since copper is by electrolsyis transferred from this plate to the other plate, it follows that only the lines of the drawing can be attacked. A battery of two cells is sufficient for this purpose. When the plate has been bitten to the depth of a millimeter it is removed from the bath and treated with hydrochloric acid, to remove traces of oxide of copper in the lines of the drawing. It is then washed with water and suspended in a bath of nickel and silver, and connected with the negative pole of the battery. The positive pole now consists of a plate of platinum. The silver or nickel deposits wherever the copper has been attacked, and the depressions are soon filled with the foreign metal. The plate is then polished, and looks like one which has been damascened by hand.

SCIENTIFIC EXPERTS AS WITNESSES.—Let us look at this question as it presents itself to men of science, alike to the chemist, the physicist, the mechanician, the geologist, the physician and the microscopist, though certainly not to the astronomer, who is in no danger of being called, as such, to give his testimony. The expert occupies a totally anomalous position in court. Technically he is a mere witness; practically he is something between a witness and an advocate, sharing the responsibilities of both, but without the privileges of the latter. He has to instruct counsel before the trial and to prompt him during its course. But in cross-examination he is the more open to insult because the court does not see clearly how he arrives at his conclusions, and suspects whatever it does not understand. The late Dr. R. Angus Smith complained of being "contemptuously compelled to herd with thieves and scoundrels in a witness-box." He adds: "I have seen barristers speaking to a scientific witness in such a way as to show that to them a witness was always an inferior person." Surely every person who has been present at a technical trial, or has had to appear as an expert in a poisoning, a patent, or an adulteration case, will be able to confirm this from his own observation and experienee.

Now it may, perhaps, be cynically hinted that men of science should be willing to bear all this annoyance for the public good. But is it for the public good? In the first place, not a few of the most eminent men in every department of science distinctly and peremptorily refuse to be mixed up in any affair which may expose them to cross-examination. "I will investigate the matter, if you wish it, and will give you a report for your guidance, but only on the distinct understanding that I am not to enter the witness-box." Such in substance is the decision of not a few men of the highest reputation and the most sterling integrity. Certainly it is not for the interests of justice to render it impossible for such men to give the court the benefit of their knowledge.

Further, the spectacle of two men of standing contradicting or seeming to contradict each other in the interest of their respective clients is a grave scandal. Men of the world are tempted to say that "Science can lay but little claim to certainty, and is rather a mass of doubtful speculations than a body of demonstrable truth." To us, at least, there is nothing more saddening than to read the trial of a notorious poisoner, or the report of a great patent case, especially if taken along with the comments of the press and of society on these occasions.

Here, then, we see that our present mode of dealing with scientific evidence is found on all hands unsatisfactory. The outside public is scandalized; experts are indignant; the bench and the bar share this feeling, but unfortunately are disposed to blame the individual rather than condemn the system.

But we fear that this unanimity of dissatisfaction will vanish as soon as a remedy is seriously proposed. To that, however, we must come unless we are willing to dispense with scientific evidence altogether.

As it seems to us, the expert should be the adviser of the court, no longer acting in the interest of either party. Above all things he must be exempt from cross-examination. His evidence, or rather his conclusions, should be given in writing, and accepted just as are the decisions of the bench on points of law.

Here for the present we must invite the suggestions of our readers, hoping to arrive at some definite result from their collective wisdom.—*Chemical News.*

VAN NOSTRAND'S

# ENGINEERING MAGAZINE.

NO. CCXII.—AUGUST, 1886.—VOL. XXXV.

## MEASUREMENT OF GAS WELLS AND OTHER GAS STREAMS.

By PROFESSOR S. W. ROBINSON, Ohio State University.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

Advance Matter from the Forthcoming Report of Dr. EDWARD ORTON, State Geologist for Ohio, Professor of Geology, Ohio State University.

Some of the recently bored gas wells in Ohio are discharging gas at too high a rate to be measured conveniently with an ordinary gas anemometer, since the delicacy of the instrument is such that it cannot stand the violence of the current. To use it would require reduction of velocity by increasing the diameter of the stream of flowing gas from the well. This may be done by means of flaring tubes fastened to the well mouth, which, however, is attended with some cost and trouble, the avoidance of which is desirable. To this end I was invited by the State Geologist, Dr. Edward Orton, to consider the question of gas well measurement.

The correct measurement of such a gas stream, where the temperature, density and velocity are all unknown, appeared to be a matter of considerable difficulty, even when the anemometer could be applied, because that instrument could make known only one of the unknown quantities, viz.; the velocity. The density being still unknown, the weight of gas discharged per minute could not be determined; and as the well mouth temperature is also still unknown, the density at that temperature cannot be calculated, even if the specific gravity of the gas is known.

Among the various appliances which suggested themselves for application was the Pitot's tube, a shunt, Bunsen's effusion principle for density of shunted gas, and a thermometer enclosed in an open tube, nearly closed at the rear, to be presented as is the Pitot's tube.

On investigation, the Pitot's tube was found to give the value of the product of the density by the square of the velocity. Had it given the density and velocity both to the same exponent in the product, the weight per second could have been found by simply multiplying by the area of the well mouth; but that not being the case, it was necessary to find the density, or the specific gravity which will serve as well, in the well mouth, either directly or calculate it from that of the gas at ordinary conditions. Measuring the velocity by the anemometer would serve, but the use of this instrument was what was to be avoided. By using the shunt of known area of mouth, and storing the gas for a definite time of flow through the shunt, the gas being allowed to gain ordinary conditions, the weight or volume per second for the well could be found from the shunt alone by multiplying the weight or volume per second shunted by the ratio of areas of well mouth and shunt mouth.

This shunt device was therefore considered favorably, until some experimental

measures were made. But the testing of the devices showed that the shunt could not be relied upon generally, for the reason that the gas sometimes carries oil from the well, which oil would smut the shunt orifice and modify to an unknown degree, the effective area of the shunt mouth, and correspondingly vitiate the results in such cases. In the Pitot's tube tests the instrument was found to be thoroughly reliable for what it gave, regardless of the heterogeneity of the fluid flowing; and the temperature of the gas could be estimated with some degree of approximation, since the pipes would sometimes freeze the water condensed upon them and sometimes not, at all the wells examined during the testing of the instruments. Also, the Pitot's tube, for convenience of application cannot be excelled, as the completion of an observation is but the work of a moment, regardless of condition of orifice. The encased thermometer was not applied at gas wells, though it has been well tested in connection with Westinghouse air apparatus.

As all these appliances will doubtless be found useful in the measurement of the streams of gas from gas wells, and of other gas currents, a description of each and the formulas for reduction of observations will be given.

THE PITOT'S TUBE.

This tube takes its name from the inventor, Pitot, who made it known to the French Academy of Sciences in 1732. See Morin's "Hydraulics," page 131. It is shown in all its simplicity and essential principles in Fig. 1, in position for determining the velocity of a current of water flowing along its bed with the free surface at *b*. The instrument, as here shown, consists simply of a plain piece of glass tube, L shaped, placed with an open mouth, *a*, presented directly toward the current, while the other end reaches above the surface at *b*. Now, when the water drives against the open end *a*, a pressure results from the impact, which causes the water to rise in the branch *bc*, to a height *h*, which height is to be used as a head by which, in some way, to calculate the velocity. Pitot concluded that this head was simply that due to the velocity *v* of the current, so that

$$v^2 = 2gh,$$

where $g$ is the acceleration of gravity. This formula is that for falling bodies, and also that for Torricelli's theorem for the velocity of issue of water from an orifice.

According to this, when water is flowing from an opening in the side of a tank, if the mouth of the Pitot's tube, somewhat smaller than the jet, be presented square against the jet, the water would rise in the upright branch of the tube just to the level of the surface of the water in the tank. This simple device, therefore, furnishes us a very handy means for finding the velocity in a stream of water, provided the instrument is reliable for accuracy.

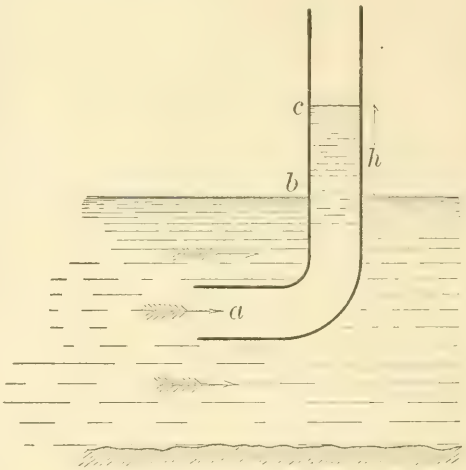



Fig. 1

For over one hundred years after its discovery, this device, so admirable for its simplicity, was regarded more for curiosity than utility, and it was believed not to be reliable for accuracy. See D'Aubuisson's "Hydraulics," (Bennett's translation) page 158. But about in 1850, M. D'Arcy, an able French hydraulic engineer, seeing in the Pitot's tube the rudiments of a most admirable hydraulic instrument, studied it with a view to reducing it to the most useful form and design for practical purposes, for a complete description of which, see Morin's "Hydraulique," page 133. The main features of this form consist of using two tubes side by side, extending from some distance above water down to de-

sired depth, then turning horizontally toward the current to where one tube terminated in a small mouth of one millimeter diameter presented direct, while the second tube was cut to a long slant and was joined upon the side of the first so as to form a smooth and converging exterior surface. Near the front termination of the second tube and about half an inch back from the open mouth of the first tube was a small hole laterally. The top ends of the tubes were glass and connected across, so that when water was drawn up by sucking the air partially from the tubes and closing a cock, the columns of water would stand at a height convenient for reading.

The instrument was thoroughly tested, and instead of being a mere toy, was found to be an instrument of precision. Also, as a more surprising fact, instead of requiring a large and varying correction factor, it was found to follow Pitot's originally stated principle exactly, viz.: $v^2=2gh$, where $h$ is the difference of level of the tops of the two columns.

It is believed that this Pitot's tube appliance has been regarded as too simple to be reliable, from the fact that it has been so little used, whereas, its simplicity, instead of condemning it, should have commended it so far as to give it more trials than it has had, which, when thus tried, it is certain, would gain a high place in the estimation of the investigator.

A further modification in form and design of this instrument was made in 1877, a full description of which was given in Van Nostrand's Magazine in vol. 18.

About in 1873, some interesting experiments were made by the writer on the use of the Pitot's tube for the determination of the velocity and form of jets of air from orifices under a head a of 2 to 4 inches of water, which experiments, as far as known to me, were the first in the application of Pitot's tube to gases. Orifices of 1 inch and 2 inches diameter were employed. The Pitot's tube in this case consisted of a glass tube about 2 feet in length bent twice at one end for an inverted U water manometer, while the other end was drawn out into a fine point, or mouth, of about five-thousandths of an inch diameter. The instrument was mounted on a slide so as to be moved by scale either across or lengthwise the jet. It is seen that by this arrangement the precise form of the longitudinal section of the jet and its velocity at any point of any cross-section could be made out. The stream was found to have a *vena contracta* much as in water jets, though shorter, and a velocity which varied from side to side in carrying the instrument across the jet, the maximum being at the middle, and very considerably higher than that at the side.

Most of the particulars respecting the jet are given in Fig. 2 for the 2-inch orifice AB, beveled to a sharp inner edge. The contracted section is near CD, and the length of the *vena contracta* is about a fourth of the diameter of the orifice, whereas in water jets, it is about a half to two-thirds. The diameter of the jet is given for every $\frac{1}{4}$ inch for the first inch, and then for the half inches. At 12 inches from the orifice, the jet was $4\frac{1}{8}$ inches in diameter. EF is the velocity curve, the velocities varying from 95 to 122 feet per second through the orifice, with the water manometer varying from 2 to 3.6 inches.

The most remarkable thing observed at this time was the fact that when the mouth of the instrument was extended some three or four inches into the tank by reaching the long neck provided on this Pitot's tube in through the orifice of issue of air under experiment, the pressure for which position being, of course, that of the interior, and then drawn slowly outward along near the middle of jet until the mouth of the Pitot's tube had reached a distance of one or two inches outside the plane of orifice of issue, the pressure indicated by the manometer was all the while precisely the same, the current through the orifice being all the while unobstructed. Here it seems certain that for mouth of tube within the tank the pressure by tube manometer is almost entirely statical, because the current here must be slight, and that at the outside of the plane of orifice the pressure indicated must be dynamic, or due to impact of air against end of tube mouth, and also that between these points there must have been a mixture of static and dynamic pressure. This strikingly illustrates the fact that as the internal pressure of a particle of fluid diminishes the stored energy increases, and that as the

potential energy due to the pressure falls the actual energy of motion rises, the sum of the two being a constant, for particles of fluid flowing through a frictionless orifice from a higher to a lower pressure. It also proves that the Pitot tube will exactly indicate a pressure or head due to velocity, when the statical pressure is eliminated, as done in the D'Arcy form of instrument. This form is that proper for use intermediate along a pipe or conduit carrying water, compressed air, or gas a considerable distance where there will be a considerable amount of statical pressure in the fluid. The latter will be eliminated in the D'Arcy form of instrument by the lateral orifice, the difference between the pressure there and at the front orifice being the dynamic pressure from which to find the velocity of fluid.

The general application of the Pitot tube to all fluids will involve consideration of variation of density of fluid under flow, so that formulas for invariable and also variable density will be required. For elastic fluids, the density will always vary, though for many cases, the variation will be so slight that it may be neglected. Thus at gas wells, when $h=4$ inches of water, the absolute pressure of the atmosphere into which the gas flows is about 400 inches, the variation of pressure being only one per cent., while in the Karg well where the pressure gauge of the Pitot's tube goes up to 15 lbs. per square inch (one atmosphere), the density will fall nearly 100 per cent. in expanding from the tube mouth to the atmosphere.

For low pressures, the apparatus shown in Fig. 3 will serve where A is the well mouth, or other orifice; BB, the Pitot tube; C, a piece of rubber hose; D, a glass tube; E, a second piece of rubber;

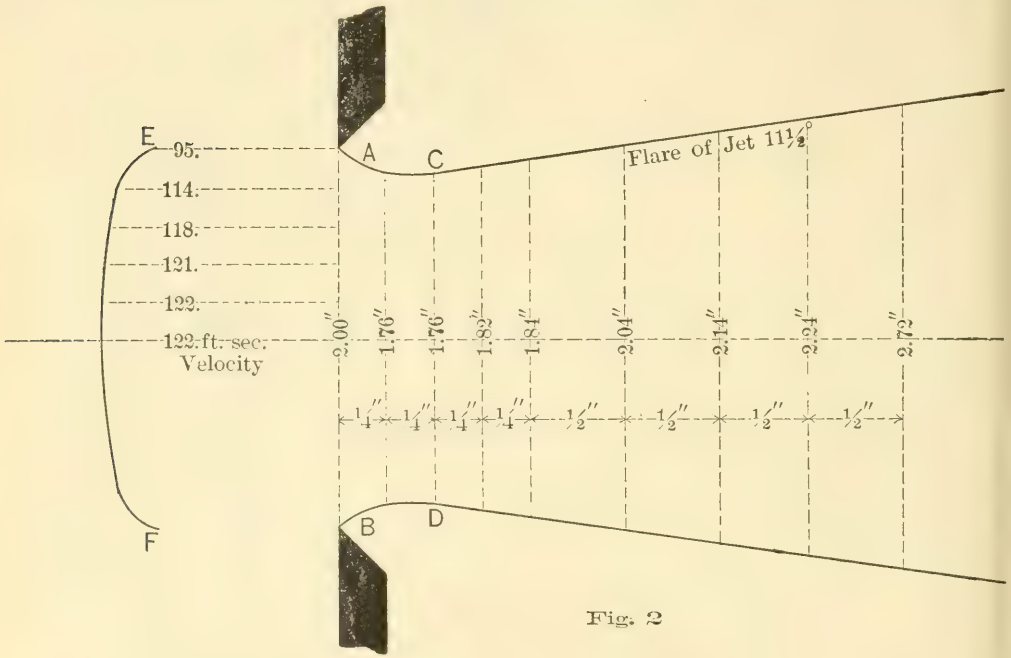



Fig. 2

and F, a second glass tube. Now, filling the part DEF with water from D to F, then it is plain that as a pressure is caused at B by impact of gas from the well, it will be transmitted to D, depressing D and raising F, giving a difference of level $DF=h=\frac{v^2}{2g}$.

By making E of some three feet length, the glass tubes can be raised F above D, as required for greater or less values of $h$. When $h$ exceeds 3 or 4 feet, it will be advisable to use a pressure gauge on the end of B, as shown in Fig. 4. In use, it is advisable to pass the mouth of

B to all portions of the well opening, and thus average for the section.

If it be suspected that there be a residual statical pressure in the gas at the mouth of the tube B, it may be tested and eliminated, if existing, by using a double tip of B, with a direct and a lateral opening, one connected to the pressure side D, and the other to the vacuum side F, of the pressure measuring device. But according to all the best authorities on flow of gases through orifices, such as Weisbach, Rankine, Zeuner, etc., the internal residual statical pressure of a jet, on entering the atmosphere, or generally on flowing from a higher to

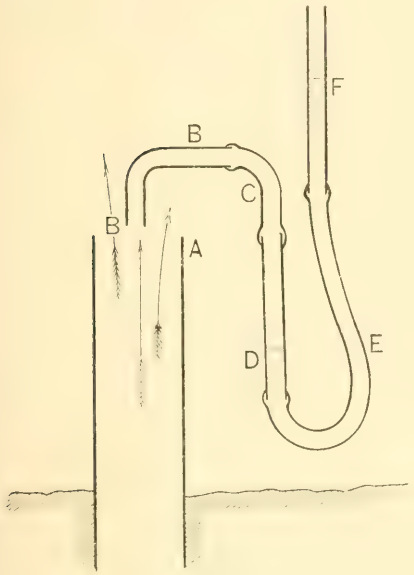



Fig. 3

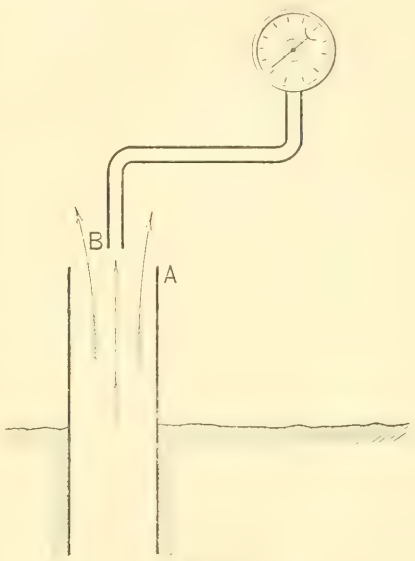



Fig. 4

a lower pressure, becomes the latter as soon as, or very soon after the plane of the orifice is passed. This fact is verified by placing the mouth end of B at right angles to and within the jet, when no appreciable pressure will be indicated.

The theory of the instrument for the case of great fall of pressure in flow of elastic fluids will be reassured, if even support is unnecessary, by citation of experiments recently made in flow of air from a receiver at 20 to 40 lbs. per square inch through an orifice to the atmosphere. Air was pumped into a Westinghouse air brake reservoir to about 40 lbs. and allowed to escape through a quarter-inch orifice beveled from the outside to the plane of the inside surface, thus securing the conditions of an orifice in a thin partition, or very nearly a theoretical orifice. An accurate pressure gauge graduated pound by pound was placed upon the receiver. A second gauge, duplicate of the first, was put on the Pitot tube, the mouth of which was 0.065 inch in diameter. The orifice was opened, and into the air stream the mouth of the Pitot's tube was placed, and the pressure of the two gauges noted simultaneously as the air escaped, and the pressure run down. The gauges kept exactly together, as long as the Pitot tube mouth was fairly within the current and not over one and a-half diameters of orifice distant from the orifice.

Three other like experiments were made and noted, the figures for which are given in the following table. The mouth of the Pitot tube, in each case, reached about an inch into the receiver, and then was withdrawn step by step, as the pressures were noted, the note "at orifice," meaning that the tube mouth was at the plane of orifice, and "$\frac{1}{8}$" out," meaning one-eight inch outside of plane of orifice but always in the jet.

TABLE OF SIMULTANEOUS RECEIVER AND PITOT TUBE PRESSURES.

First Experiment.

| Receiver | Tube | |
|---|---|---|
| 30 | $29\frac{1}{2}$ | |
| $26\frac{1}{2}$ | $26\frac{1}{2}$ | |
| 24 | 24 | |
| 22 | $22\frac{1}{2}$ | at orifice. |
| 20 | $19\frac{1}{2}$ | out. |
| 18 | $17\frac{1}{2}$ | |

Second Experiment.

| Receiver | Tube | |
|---|---|---|
| $27\frac{1}{2}$ | $26\frac{1}{2}$ | |
| $24\frac{1}{2}$ | 24 | |
| 21 | 21 | at orifice. |
| 20 | $19\frac{1}{2}$ | $\frac{1}{8}''$ out. |
| 17 | $15\frac{1}{2}$ | $\frac{1}{2}''$ out. |
| $16\frac{1}{2}$ | 14 | $\frac{3}{4}''$ out. |

Third Experiment.

| Receiver | Tube | |
|---|---|---|
| 28 | $27\frac{1}{2}$ | |
| 25 | $24\frac{1}{2}$ | |
| $22\frac{1}{2}$ | $22\frac{1}{2}$ | at orifice. |
| $20\frac{1}{2}$ | $20\frac{1}{2}$ | $\frac{1}{8}''$ out. |
| 18 | $16\frac{1}{2}$ | $\frac{7}{16}''$ out. |
| $16\frac{1}{2}$ | 13 | $1''$ out. |

These figures show that the pressure in the receiver and that in the Pitot tube agree with practical exactness, as the mouth of the Pitot tube is withdrawn from the position extended an inch within until the mouth is over $\frac{1}{8}$ inch outside (a diameter by other experiments and probably the same here, viz.: $\frac{1}{4}$ inch); and that when the tube mouth is four diameters outside, its pressure is up to $\frac{3}{4}$ that of the receiver. Besides this, in determinations of tube pressure at gas wells, it was found that the same pressure was got whenever the mouth of the tube ranged within a diameter of well mouth in distance from it.

In the above experiments, the jet of air was forced direct and square against the Pitot tube mouth when outside, so that the cause of the pressure was wholly dynamic, and not at all static; that is, that at points just in front of the orifice, there is no residual statical pressure. Experiments were made to test this point by making a D'Arcy form of double mouth Pitot tube, one mouth being direct as before, and the other on the side of the tip, as shown in Fig. 5, at A and B respectively. Small holes were drilled back from the mouths A and B, and entirely independent of each other and connected at the rear, one with one standard gauge at C, and the other with another at D, all combined into a portable device.

Now, the mouth A will communicate

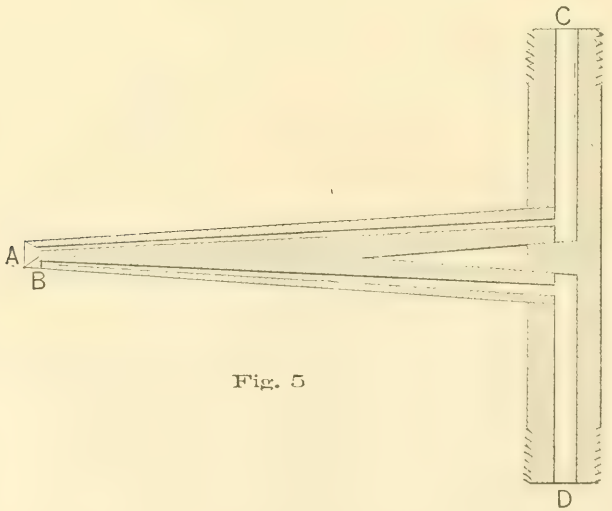



Fig. 5

the pressure due to direct impact, while at B, the moving fluid will tend to move straight by, and will cause no action at

B, except for the lateral statical pressure of the jet at the point B, as concluded by D'Arcy for his improved tube for gauging streams of water.

This tip AB, Fig. 5, was inserted to some distance through the orifice into the receiver and then withdrawn step by step, until some distance outside; and the indications by both gauges noted simultaneously at the steps, where the tip was held steady for a few seconds.

When AB is within the receiver, the two gauges should, of course, indicate nearly the same, while when outside, the gauge for B should stand at zero. Results of test are given in the following table:

plane of the orifice, to zero at the contracted section; at which latter section, therefore, there is no residual statical pressure. In cases where there is no *vena contracta*, as for the cylindrical ajutage, for instance, or the mouth of cylindric pipes, there can be no residual statical pressure at the plane of the exit mouth, the contracted section in this case.

The fall of pressure from 22 to 14 for the direct mouth A of the 3d experiment was not due to the withdrawal of the tube from the receiver, nor in any other experiment; but the fall was owing to the exhaustion of the receiver of air on account of the flow; the pump not being able to maintain pressure.

TABLE OF SIMULTANEOUS DIRECT AND SIDE MOUTH PITOT TUBE PRESSURES, TO TEST FOR STATICAL PRESSURE OF JET.

| Distance of Side Outlet from Plane of Orifice. | Pressure by Gauge connected with Mouth. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1st Experiment. | | 2d Experiment. | | 3d Experiment. | | 4th Experiment. | |
| | Direct. | Side. | Direct. | Side. | Direct. | Side. | Direct. | Side. |
| Inside, $\frac{3}{8}$-inch..... | 24 | 25 | 26 | 27 | — | — | — | — |
| " $\frac{1}{4}$ " ..... | 22 | 23 | 24 | 25 | 22 | 23 | — | — |
| " $\frac{1}{16}$ " ..... | 20 | 21 | 22 | 23 | 20 | 23 | 21 | 22 |
| At orifice..... | 17 | 18 | 20 | 19 | 19 | 20 | 20 | 19 |
| Out, $\frac{1}{16}$-inch..... | — | — | — | — | 17 | 15 | 18 | 13 |
| " $\frac{1}{8}$ " ..... | 14 | 0 | 19 | 1 | 16 | 0 | 16 | 0 |
| " $\frac{1}{4}$ " ..... | 12 | 0 | 15 | 0 | 14 | 0 | 15 | 0 |

In examining this table, consider the 3d experiment for instance. When the side mouth B was a quarter of an inch inside the receiver, the gauge for that mouth indicated 23 lbs. per square inch, while the gauge for the direct mouth A indicated 22 lbs. When B was at the plane of the orifice its gauge stood at 20, and that for A, at 19 lbs. For B $\frac{1}{16}$-inch outside the plane of the orifice its gauge stood at 15 lbs., and that for A at 17 lbs. Again, for B $\frac{1}{8}$-inch outside, its gauge stood at zero, while that for A stood at 16 lbs.; the lateral pressure, or statical pressure, of jet vanishing entirely within the space of a sixteenth of an inch, which space lies about at the terminus of the *vena contracta*, or about at CD, Fig. 2.

Hence the two gauges practicably agree within the receiver, and that for B falling from agreement with A, at the

From all the above facts of experiment for high and low pressures we are forced to the conclusion that the Pitot tube is a thoroughly reliable instrument for determining the pressure or dynamic head to which the velocity of flow is due, and that the original notions announced by Pitot respecting the relation of velocity and head are rigorously substantiated, not only for flowing water, as he announced, or even other liquids, but for all kinds of fluids, elastic as well as inelastic, except, possibly, for viscous fluids like molasses or tar.

It appears, then, that in calculating the velocity of flow from a receiver, the pressure to be used for head may just as well be taken from the Pitot tube as from the receiver direct, and the same formula is to be used for the one as for the other. Hence, where there is no receiver to

gauge from, we may proceed with the Pitot tube.

VELOCITY UNDER SMALL PRESSURES.

To calculate the velocity of flow for fluids where the change of density during flow can be neglected, we employ the formula of Pitot, but for gases, the head $h$ must be found on the supposition that $h$ is the depth of the gas from the orifice up to an imaginary free surface throughout which the density is uniform and the same as at the orifice. Then the pressure per unit surface upon the orifice will be

$$p_1-p_2=\delta h \text{ or } h=\frac{p_1-p_2}{\delta} \qquad (2)$$

where $\delta$ is the specific density of the fluid flowing, or the weight per cubic unit. Thus, for air flowing from a receiver where the absolute pressure is $p_1$ into a space where the absolute pressure is $p_2$, the effective pressure will be $p_1-p_2$, as above. Hence

$$v^2=2g\frac{p_1-p_2}{\delta} \qquad (3)$$

a general formula for case of slight variation of $\delta$.

At the mouth of a gas well the pressure of the gas flowing is the atmospheric and its density is

$$\delta=.0807\ \mathrm{S}g.\frac{\tau_0}{\tau} \qquad (4)$$

where $\mathrm{S}g.$ is the specific gravity of the gas, air being 1, $\tau_0$=the absolute temperature of melting ice, and $\tau$ the absolute temperature of the flowing gas. But

$$\frac{\tau_0}{\tau}=\frac{273}{273+t}\text{Cent.}^\circ=\frac{493}{461+t}\text{Fahr.}^\circ$$

Introducing these into the Pitot formula and taking $2g=64.3$, we get for units in feet,

$$v=338.7\left(1+\frac{t}{546+t}\right)\sqrt{\frac{p_1-p_2}{\mathrm{S}g.}},\text{Cent.}^\circ$$

$$=338.7\left(1+\frac{t-32}{954+t}\right)\sqrt{\frac{p_1-p_2}{\mathrm{S}g.}},\text{Fahr.}^\circ \qquad (5)$$

where $t$ is the temperature of the flowing gas.

Applying this to a gas well, $p_1-p_2$ is the effective pressure indicated by the pressure gauge, and taking the temperature at the freezing point and $\mathrm{S}g.$ at 0.6 for an approximation, we have

$$v \text{ approx.}=437.3\sqrt{p_1-p_2} \qquad (6)$$

Suppose the pressure gauge on the Pitot tube reads 1 lb. Then $p_1-p_2=1$ *lb.* and $v=437.3$ feet per second.

For small pressures, such that the water manometer is used, as in Fig. 2, 1 lb. pressure is equivalent to 27.5 nearly inches of water, and by putting $h$ the head in inches of water, we have.

$$p_1-p_2=\frac{h}{27.5},$$

$$v=64.37\left(1+\frac{t}{546+t}\right)\sqrt{\frac{h}{\mathrm{S}g}}\ \text{Cent.}^\circ$$

$$=64.37\left(1+\frac{t-32}{954+t}\right)\sqrt{\frac{h}{\mathrm{S}g}}\ \text{Fahr.}^\circ \qquad (7)$$

and taking $\mathrm{S}g=0.6$,

$$v \text{ approx.}=83.1\sqrt{h} \qquad (8)$$

Suppose the manometer gives 27.5 inches of water, =1 lb. pressure. Then (8) gives $v$=437.3 feet per second.

VELOCITY UNDER GREAT PRESSURES.

When a gas flows from a receiver into a space outside with a relativeiy large fall of pressure, the formulas for adiabatic flow of gas are to be employed for calculation. The correct formula for this is found in most of our best authorities, viz.:

$$v^2=\frac{2\,g\,\gamma}{\gamma-1}\frac{p_2}{\delta}\left\{\left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}}-1\right\} \qquad (9)$$

in which, for the present use, $p_1$=absolute pressure by Pitot's tube gauge; $p_2$= absolute pressure of air = 14.6 lbs. per square inch; $\delta$=wt. unit vol. of flowing gas at mouth of Pitot tube=$.0807\frac{\tau_0}{\tau}\mathrm{S}g$; $\tau_0$ and $\tau$=absolute temperatures, as before, $\mathrm{S}g$=specific gravity of flowing gas at mouth of Pitot tube, air=1; $\gamma$=1.408; $\frac{\gamma}{\gamma-1}$=3.451; $2g$=64.3; $m^2$=value in parenthesis: then, introducing the numerical values and reducing, we obtain;

$$v=2404\frac{m}{\sqrt{\mathrm{S}g}}+\frac{t}{546+t}2404\frac{m}{\sqrt{\mathrm{S}g}},\text{for Cent}^\circ$$

and

$$v = 2404\frac{m}{\sqrt{Sg}} + \frac{t-32}{954+t}\,2404\frac{m}{\sqrt{Sg}} = \text{for Fahr.}^{\circ} \quad (10)$$

If the temperature of the flowing gas be taken at that for melting ice and $Sg$ at 0.6, we obtain the approximate formula

$$v \text{ approx.} = 2404m \quad (11)$$

To facilitate the calculations with these formulas, the value of $m$ in terms of the ratio of pressures $p_1$ to $p_2$ may be tabulated as follows:

| $\frac{p_1}{p_2}$ | $m$. | $m^2$. |
|---|---|---|
| 1.035 | .1000 | .01 |
| 1.071 | .1414 | .02 |
| 1.107 | .1732 | .03 |
| 1.145 | .2000 | .04 |
| 1.183 | .2236 | .05 |
| 1.222 | .2449 | .06 |
| 1.263 | .2646 | .07 |
| 1.304 | .2828 | .08 |
| 1.346 | .3000 | .09 |
| 1.389 | .3162 | .10 |
| 1.433 | .3317 | .11 |
| 1.478 | .3464 | .12 |
| 1.525 | .3606 | .13 |
| 1.572 | .3742 | .14 |
| 1.620 | .3873 | .15 |
| 1.669 | .4000 | .16 |
| 1.719 | .4132 | .17 |
| 1.770 | .4243 | .18 |
| 1.822 | .4359 | .19 |
| 1.876 | .4472 | .20 |
| 1.930 | .4585 | .21 |
| 1.986 | .4690 | .22 |
| 2.043 | .4799 | .23 |
| 2.101 | .4899 | .24 |
| 2.160 | .5000 | .25 |

The bracketed quantity in equation (9) may be put in the form

$$\left\{\left(1+\frac{p_1-p_2}{p_2}\right)^{\frac{\gamma-1}{\gamma}}-1\right\}.$$

Developing by the binomial theorem, and (9) becomes

$$v^2 = 2g\frac{p_1-p_2}{\delta}\left[1-\frac{p_1-p_2}{2\gamma p_2}+\frac{\gamma+1}{6\gamma^2}\frac{(p_1-p_2)}{p_2}-\&c.\right] \quad (12)$$

the first term of which is the same as (3), and the remaining terms may be regarded as corrections to (3), modifying it as required for the change from constant to varying density under flow. From this it is seen that for adiabatic flow, the formula for constant density gives values which are too high.

CONFIRMATION OF THE FORMULAS.

The shunt has been used to verify results by the Pitot tube in the flow of air and of gas under variable density.

1. For air, the Westinghouse Reservoir was charged with compressed air to 17 lbs. per square inch, and the one-fourth inch orifice opened for discharge, while the shunt mouth was introduced into the issuing jet for eight seconds and the pressure noted for every two seconds as follows:

VERIFYING EXPERIMENT WITH SHUNT.

| Seconds. | Receiver Pressure. | Means by Pairs. | Calculated Velocities. |
|---|---|---|---|
| 0 | 17 | | |
| | | 16.50 | 1115 |
| 2 | 16 | | |
| | | 15.75 | 1083 |
| 4 | 15½ | | |
| | | 15.25 | 1070 |
| 6 | 15 | | |
| | | 14.75 | 1056 |
| 8 | 14½ | | |

Mean velocity, ft. per sec., calculated 1081
Velocity by the shunt," " " 1006

The shunt orifice was 0.065 inch diameter, and the shunted air was 40.08 cubic inches per second. The shunt orifice (explained later) was one of no resistance, and the gas bag and connecting pipes offered no appreciable resistance. The shunt orifice, however, could never have a greater effective area than that measured, while slight traces of dust would make it less. The possibility of some lingering dust and the resistance of connections would account for part of the difference of velocities 1081 and 1006 observed.

It is to be observed that the shunt is theoretically a positive measurer of velocity, so that the 1,006 feet may be regarded as positively not far from, though probably less than the actual velocity.

Hence the 1,083 feet velocity given by the Pitot tube calculation is to be regarded as a fairly reliable result.

2. At a gas well the Pitot tube and shunt were both applied in quick succession, each several times, with mean results as follows:

Velocity by tube=1178 feet per second.
" " shunt=1111 " "

The shunt mouth was cleaned out each time applied, to clear it of possible obstructions, though no evidence was found of interfering matter.

3. At a second gas well the results were as follows:

Velocity by tube=1,016 feet per second.
" " shunt= 876 " "

This well carried traces of oil along with the gas, so that the hand placed in the jet in a few seconds would be smutted with oil. Hence, there can be no doubt but that the oil deposit in the shunt mouth noticed at the time had a very appreciable effect in cutting short the flow by shunt. This discrepancy of results is therefore expected, and that fact here serves for verification.

PITOT TUBE MOUTH.

By regarding the pressure obtained by this instrument as due to the impact against the open mouth, it is easily seen that the amount of action is proportional to the area of mouth, so that this area is independent of the observed pressure. In the experiments, the largest mouth was $\frac{7}{16}$-inch, another was $\frac{1}{4}$-inch, and the smallest was 0.065 inch in diameter, giving the following results at the Karg gas well where all were tried:

TEST FOR SIZE OF TUBE MOUTH.

| | Mouth 0.065 inch diameter. | Mouth $\frac{1}{4}$-inch diameter. | Mouth $\frac{7}{8}$-inch diameter. |
|---|---|---|---|
| 1, side..... | 12 | 13 | — |
| 2..... | 14 | 15 | 14.5 |
| 3, center.... | 15.5 | 15 | 15 |
| 4..... | 14 | 14.5 | 10 |
| 5, side..... | 9 | 9.5 | — |

Each figure in the table is the mean of two observations. The observed pressures agree well for the different sizes, and indicate absolute independence of size of tube mouth.

The small mouth is the one used for the shunt. All were formed sharp, or very nearly so, at the front end of tube around the mouth, and no experiments were made with a dull mouth rim.

THE SHUNT.

A shunt properly constructed for this purpose should offer no resistance to the movement of the fluid, so that when a particle of shunted gas has just fairly entered the shunt mouth, its velocity should be the same as that of the stream around it.

The connecting tube, for as great a portion of length as possible between mouth and collecting bag, should be large, and yet it should be gradually enlarged from the point or mouth in order not to present a blunt end for impact of gas and thus modify the flow into its mouth.

To thus secure a tapering tip and at the same time an orifice of no resistance, the device of making the inside with a gradual flare for an inch or two was resorted to, and such a flare that the resulting loss of velocity and consequent loss of energy of motion in the passage would just compensate for the frictional resistance to be overcome in this small part of the passage. After thus getting a suitable distance from the mouth, a sudden enlargement was made to such size as to reduce the remainder of the connecting pipes to practically no resistance.

If $v$=velocity of fluid at the mouth end, and $v'$ that at the larger end where the sudden enlargement occurs, then the loss of energy of motion between the points will be

$$\tfrac{1}{2}\mathrm{M}(v^2-v'^2)$$

where $$\mathrm{M}=\frac{\delta a v}{g}$$ per second.

$\delta$ being the density and $a$ the area of passage way.

The work overcome in frictional resistance per second will be the force into the space.

$$\mathrm{F}v=f\delta\pi dl\frac{v^2}{2g}v=\frac{\delta a v}{2g}(v^2-v'^2) \quad (12)$$

where $f$ is the coefficient of fluid friction, $d$ the diameter of the narrow part, $g$ the passage, and $l$ its length. Observing that $av$ = the volume per second $=\frac{\pi d^2 v}{4}$, and constant for at least an infinitesimal length, we reduce the above to

$$2a\frac{v-v'}{v}=\pi dfl,$$

or $$l=\frac{d'-d}{f} \qquad (13)$$

The same result would have been obtained had the equations been worked out for an infinitesimal length and variable density, and then integrated.

The final result shows that the difference of diameter at the opposite ends of the flaring smaller part of the passage is independent of the total diameter.

The value of $f$ is about 0.006. Now, making $d'-d=\frac{1}{100}$ of an inch, then $l=$ 1.67 inches. These are the figures according to which the shunt tip experimented with was made. The diameter of the mouth at the tip was 0.065 inches, and at the 1.67 inches distance from the tip the passage was 0.075 inches, where it quickly enlarged to $\frac{1}{4}$-inch, the size for $2\frac{1}{2}$ inches: beyond which, for about 18 inches, it was about $\frac{3}{8}$-inch, where the light rubber bag was attached for catching the shunted gas. This bag was made especially for the purpose, of very thin "dental rubber."

When collected, the gas was measured by running it through an aspirator. When thus measured its temperature should be noted.

On account of the passage-way in the shunt being formed as one of no resistance, the gas collected per second is regarded as having flown through the shunt mouth at the same rate that it did outside the mouth, or with the normal velocity of the gas at the well mouth.

### QUANTITY OF GAS DISCHARGED.

The quantity of discharge should be estimated at some standard temperature at which the gas is supposed to stand as if retained collected in a gas-holder, say 60° Fahr. But while the gas is flowing, its temperature will almost always be much lower, on account of the expansion which accompanies the flow. For instance, in the shunt verifying experiment of the air issuing from the receiver at initial 17 lbs. apparent pressure, the density of the stream of air just outside the plane of the orifice was 0.0937, instead of 0.0749 of the surrounding air into which the receiver was discharged, and the volume $av$ calculated by using the velocity $v=1083$ would require to be increased about 25 per cent. to obtain the volume of the discharged air on the supposition of being collected and retained in a gas-holder at atmospheric pressure, and temperature of 60° Fahr.

The temperature of the air in the same jet from the receiver was about 38° below zero Fahr., which low temperature is to account for the high density in the jet.

Taking V for the volume discharged per second, then

$$V=Av\frac{\tau_0}{\tau},$$

where A=area of the stream of gas being measured, as for instance, that at the gas well mouth, or of the well mouth itself, $\tau_2$ the absolute temperature of the gas when stored, and $\tau$ that of the gas in the stream. But

$$\frac{\tau_2}{\tau}=\frac{273+t_2}{273+t}=1+\frac{t_2-t}{273+t}\ \text{Cent.}^\circ$$

$$=1+\frac{t_2-t}{461+t}\ \text{Fahr.}^\circ \qquad (15)$$

Hence

$$V=Av+Av\frac{t_2-t}{273+t}\ \text{Cent.}^\circ$$

$$=Av+Av\frac{t_2-t}{461+t}\ \text{Fahr.}^\circ \qquad (16)$$

The volume discharged per day of 24 hours for dimensions in feet will be

$$\text{Vol. per day}=86400\ V. \qquad (17)$$

### THE ENCASED THERMOMETER; OR TEMPERATURE OF STREAM.

In the impact of the gas against the open end of a tube, it is just as true, from theoretical grounds, at least, that the temperature will be restored as well as the pressure. That is referring to the case of the air issuing from the receiver through the orifice, the pressure in the Pitot's tube by impact has been shown to be up just to that in the receiver. Consequently, the air was compressed back to its original conditions as to temperature and volume very nearly, since the time for acquiring heat by a particle in the act of passing out against the tube mouth could not much exceed the 50 thousandth part of a second. The same is true of the density.

About a dozen experiments were made to test the question as to restoration of temperature in the cup mouth by means of an encased thermometer arrangement shown in Fig. 6. A glass tube, BC,

about $\frac{3}{4}$ inch diameter was drawn down at A to about $\frac{1}{8}$ inch diameter, for the mouth to present to the $\frac{1}{4}$ orifice, O, in the Westinghouse apparatus. Inside of AC is shown the encased thermometer supported in the center of the tube, and with its bulb, B, as near as practicable to A. In the plug at C is a small hole to allow a current to flow past the thermometer, so that the air in AC will not have time to be modified in temperature after being compressed at A, before it surrounds the thermometer bulb at B for determination of temperature.

There was no thermometer in the receiver to show its temperature. In experimenting, the pressure would fall, in each experiment, from between 30 and 40 lbs. per square inch to about 8 or 10, owing to which, the temperature would, of course, fall in the receiver. But at the same time, air was being pumped in as fast as the pump would work. Under these conditions, it is difficult to tell what the temperature in the receiver at any time was, but as the room was at about 25° C., it is probable that the interior of the receiver ranged from 15° to 20° C.

Exposing the naked thermometer bulb to the jet, while pressure fell from 35 to 10 lbs., the mercury fell to from 3 to 6 degrees below zero C.; but the real temperature of the jet must have been very much lower, from the fact that ice would form on the bulb and not melt nor even become moist for several minutes after removal of thermometer from jet and exposure to the air of the room, thus proving a great fall of temperature in the act of expansion at the orifice O. The actual temperature of jet could not be expected to be indicated by a naked thermometer in this way, for the reason that the impact of air upon the thermometer bulb, and friction of the flowing air passing it, would give such a tendency to elevation of temperature as to utterly defeat the effort to determine definite knowledge as to the actual temperature of the jet by means of a naked thermometer.

But in presenting the mouth of the *encased* thermometer to the jet, the mercury would stand very nearly steady at about 16° to 22° C., sometimes not falling a single degree. As this temperature was not far from that within the receiver, together with the fact that the naked thermometer would fall from 20° to 25° lower and yet not reach the limit, it appears that the encased thermometer is to be relied upon for indicating the temperature in the receiver.

Hence, from all the facts of experiment, and considerations above noted, we are prepared to state the following more general principle; for nonviscous, elastic or nonelastic fluids, viz.:

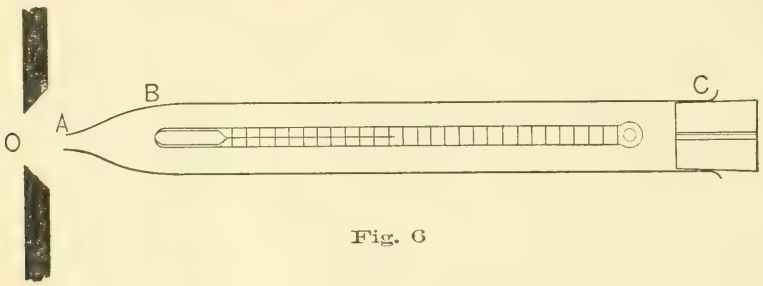



Fig. 6

*When any fluid flows from a higher to lower pressure through a frictionless passage, the portion caught direct in a cup mouth will be restored to its original conditions as to pressure, temperature and density.*

By using a tube of some nonconducting material, like pasteboard, or *papier maché*, for the casing Fig. 6, extending from A to some distance past the thermometer bulb, and then glass, better results would doubtless be obtained than for all glass, though glass would be much better than metal.

The temperature of the encased thermometer, as well as the pressure by the Pitot tube, for any stream of gas observed, should be regarded as that of the *equivalent receiver*, that is, a receiver from which the same gas would flow to

produce the same jet as that observed for which the temperature and pressure would be that of the encased thermometer and Pitot tube.

This fact is to be taken advantage of for securing the temperature of the flowing jet by calculation from the temperature as observed from a thermometer placed in the non-conductor tube.

Then the temperature of the stream of gas can be calculated from the well-known relation for adiabatic expansion,

$$\left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}} = 1 + m^2 = \frac{\tau_1}{\tau} = 1 + \frac{t_1 - t}{273 + t} \text{Cent.}^\circ$$

whence

$$t = \frac{t_1 - 273m^2}{1 + m^2} \text{Cent.}^\circ = \frac{t_1 - 461m^2}{1 + m^2} \text{Fahr.}^\circ$$

where $t_1$ is the temperature observed from the encased thermometer, $m$ the value found from the table given above, and $t$ the temperature of the stream. When the result for $t$ comes out negative, it is to be read "below zero."

This value of $t$ is to be used in (5), (7) or (10).

DENSITY, OR SPECIFIC GRAVITY.

As the formulas for calculating the velocity of flow contain the specific gravity of the gas, some convenient way of finding it is desirable. Where the analysis of the gas in question is not known, Bunsen's Effusion Principle, as already stated, may be applied. A simple way of doing this is to draw a $\frac{3}{8}$-inch glass tube down blunt to a fine orifice, put this into a cork, orifice up, and the cork into a bottle with the bottom knocked out. Then fill the bottle with water set it into a common plate filled with water. Now, let the water flow out over the edge of the plate and draw air in through the effusion orifice at the top of the tube in the cork and note the time. Then fill the bottle again, and similarly allow the gas in question to flow through the effusion orifice and empty the bottle, noting the time of flow. Then Bunsen's principle makes the densities proportional to the squares of the times, and the specific gravity equal to the ratio of the squares of the times.

A mark may be placed on the neck and near the bottom of the bottle to start and stop at; and a piece of rubber hose may be stuck upon the effusion tube and gripped to prevent flow till ready.

The gas may be caught from the gas well by a shunt in a light bag for the effusion tube to draw from in observing for time of effusion of gas, care being taken to get all air from the connections.

APPLICATIONS.

Primarily in this investigation, the object was to measure gas wells, but the appliances are applicable to other streams or currents of gas, even where the fluid is of indefinite extent, as in high winds. Several instances are known of failures of wind anemometers at the critical time of a most valuable record, because of delicacy, complexity, etc., of instrument. In the Pitot tube, we find an instrument of the greatest possible simplicity and stability, one not having a single moving part exposed to the wind.

Thus, to find a reliable wind velocity or pressure of the tornado, put up on strong iron frame-work, several Pitot tube points radiating in different directions, including up and down, each with double mouth, one direct and one lateral, connected properly with a gauge as above explained, with a maximum indicator. This contrivance could be left to stand by itself year after year, observed or not. Finally, the maximum wind pressure with direction could be read off. These could be located at various points about the country, any one of which struck by a cyclone, could make known the various interesting facts so much desired, as to pressure, velocity, variety of direction, lifting power, etc.

A double mouth tube placed inside a conducting pipe would show by gauge located at any convenient situation, the velocity in the pipe.

GAS WELLS.

The following results of application to gas wells can be given:

*Karg Well*, Findlay, Ohio.

At well mouth, Pitot tube pressure, 15 lbs. per square inch.

$$\frac{p_1}{p_2} = \frac{29.6}{14.6} = 1.592$$

$m = 0.4876$

$v = 1513$ ft. per sec.

A = .0873 square ft.

Cubic ft. per day = 12,080,000.

*Cory Well*, Findlay, Ohio.

End of 2″ pipe, 21 ft. from well mouth.

Pitot tube pressure, 9.25 lbs.

$$\frac{p_1}{p_2}=\frac{23.25}{14.6}=2.028.$$

$m=0.3797$

$v=1178$ ft. per sec.

A=.0308 square ft.

Cubic ft. per day=3,318,000.

By shunt at this well, the velocity was 1111. feet per second, by three observations giving 48.3, 45.2 and 44.6 cubic inches per second, respectively.

*Briggs Well*, Findlay, Ohio.

April 17th, 1886.

End of 2″ pipe, 91 ft. from well mouth.

Pitot tube pressure=6.5 lbs.

$$\frac{p_1}{p_2}=\frac{21.1}{14.6}=1.445$$

$m=.3274$

$v=1016$ feet per second.

A=.0276 square feet.

Cubic ft. per day=2,565,000

From a second stratum above the first, water gauge,

| *h.* Inches. | Diameter. Inches. | Velocity. Feet. | Cubic feet per day. |
|---|---|---|---|
| 0.48 | $2\frac{3}{4}$ | 57.7 | 206,100 |
| 0.5625 | $2\frac{1}{2}$ | 62.61 | 184,400 |
| 29.0 | $\frac{15}{16}$ | 449.5 | 186,200 |
| | | By Anemometer..... | 186,400 |

These four measurements are for the same stream of gas.

*Jones Well*, Findlay, Ohio.

April 17th, 1886.

Pressure by water gauge,

| *h.* Inches. | Diameter. Inches. | Velocity. Feet. | Cubic feet per day. |
|---|---|---|---|
| 0.3125 | $7\frac{15}{16}$ | 46.45 | 1,444,000 |
| 3.79 | $3\frac{3}{8}$ | 161.7 | 918,600 |
| | | Mean..... | 1,181,300 |
| | | By Anemometer..... | 1,159,200 |

The jet was here very irregular, the gas being forced out at right angles through a valve, from the main well tubing; the first result being got from the end of a flaring funnel, and the second from the valve mouth direct. The several anemometer results also differed greatly among themselves.

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## STEEL SLEEPERS FOR PERMANENT WAY.

By J. W. POST.

Translated from Schweizerischer Bauzeitung, for Abstracts of the Institution of Civil Engineers.

From a railway point of view the introduction of steel sleepers is good, because the average life of a sleeper is increased, the price of wood sleepers is lowered by the competition, and in industrial countries the making of a ton of steel sleepers brings over the railways a traffic of about ten tons of raw material.

The first trials of hard steel-sleepers were not encouraging, and some railway companies gave them up at once. Other companies laid test lengths on different systems, inspected them carefully and kept statistics of the cost of maintenance. Especially was this done on the Dutch and German railways, and with some success, and to these trials are due the results and experience now available.

Since the Bessemer, Thomas and Siemens processes have rivaled each other in producing mild steel, steel sleepers have come much more into competition.

It is generally agreed that:

1. The average life of good steel sleepers is considerably longer than that of the best wooden ones.

2. The width of gauge is better maintained with steel sleepers.

3. The cost of maintenance of permanent way on steel sleepers remains almost constant after the second year, but on wood sleepers increases constantly with age, so that the average cost of the latter is greater.

4. There are systems of fastenings on steel sleepers which are at once safer and

more easily maintained than those for wood sleepers.

5. A good steel sleeper should not cost more than from 125 to 150 per cent. of the cost of a wood sleeper.

6. The "old material" value of a steel sleeper is greater than that of a wood sleeper.

If, for comparison of the relative cost per mile of steel and wood, account is taken of the manufacture, transport, laying, maintenance, interest (lately the low rate of interest has told in favor of the lasting material), and value as scrap, it is seen that there are few countries in the world where the exclusive use of wood sleepers is really economical. For countries where climate and insects destroy wood sleepers in a few years, this is evident; but it speaks better for steel sleepers that in Holland, which produces no steel and gets wood sleepers very cheaply by sea, all the railway companies have introduced metal sleepers without any pressure from the Government

The first metal sleepers were too weak; owing to a mistaken idea that they must be as cheap as those of wood, they were made only from 55 to 66 lbs. weight, and it was not clearly seen that they were weakest where the rails rested on them, because (1) the holes of the fastening reduce the cross section; (2) the punching of the holes makes the metal round them more or less brittle; (3) the foot of the rail and the fastenings eat in time into the top of the sleeper; (4) with rational beating up of the ballast the moment of reaction of the ballast is a maximum at the cross-section where the wheel load is applied; (5) the impulse of the moving is transferred directly to the sleepers at these places; and (6) in the various systems the material suffers most at these places during the forming of the 1 in 20 slope, to give the cant to the rail, whether that is done in the hot or cold.

The disadvantages of the sleepers being too weak soon showed, in the bending and shaking, the escape of the ballast and consequent expensive maintenance; also in the cracking of the sleepers lengthwise and crosswise where the rails rest. Some railways then introduced heavier sleepers (up to 165 lbs. weight), which lasted well, but were expensive. Various attempts to strengthen the sleeper by riveting or bolting to it plates for the rail to rest on, with or without the 1 in 20 slope, were unsuccessful because of the increased cost, or because the connection between rail and sleeper was less secure.

Latterly improvements in rolling machinery have rendered it possible to make sleepers of varying thickness, and having the 1 in 20 slope for the rail, the whole being done in the process of rolling. This improvement enables the metal to be disposed where most required, and effects a saving in weight of from 12 to 21 per cent. in the sleeper. The minimum cross-section of the sleeper is kept for about two-thirds of the length, while it is thickened under the rail and for a short distance on each side of it.

After the Netherlands State Railway Company had for some years laid test lengths of their main line on sharp curves and heavy gradients, with iron and steel sleepers of various designs, and carefully compared the cost of maintenance with that of similar lengths of line laid on new oak sleepers, they decided in favor of the mild steel sleepers, 8 feet 6 inches long, 9.25 inches wide over the extreme edges at the bottom, 2.52 inches deep for the greater part of its length but increased to 2.92 inches under the rail, and 3.23 inches at about 4 inches outside the rail, so as to give the inclination of 1 in 20 for the cant of the flat-bottomed rail which rests directly on the sleeper. Advantage was taken of the low prices of steel during the past two years to lay down large quantities of these sleepers on the Dutch, Belgian and German lines of the company. One of the district engineers in his annual report for 1884, states that on a test piece of line 1,144 yards long, on a curve of 820 yards radius and a gradient of 1 in 83, no beating up of the sleepers was required for twenty-two months ending December 31, 1884, and that the only maintenance required was one man for thirty-four days inspecting and tightening up the bolts. He states that the cost of maintenance of a steel sleeper road, three and a-half years old, is the same as that of the same age laid on wooden sleepers, but that from this point the cost of the latter increases, while the cost of the former tends to diminish, owing to the consolidation of the bed. The following advantages are claimed for the sleeper

(adopted from the St. Gothard Railway) by the Netherlands State Railway Company:

1. It is easily packed with any kind of ballast, sand, gravel, ashes or slag.

2. The triangular toe which forms the bottom edge of the sloping sides of the sleeper prevents damage to the edge during beating up, and by lowering the neutral axis of the section gives additional stiffness. It also makes the section easier to roll.

3. It gives a broad surface to the foot of the rail to rest upon.

The weight of this sleeper is 104.7 lbs., whereas a sleeper of the same strength, with a uniform instead of a varying cross-section, would weigh 15 per cent. more. The last steel sleepers ordered (July, 1885) cost at the works, including a two years' guarantee, not quite 6 francs each, or almost the same as an oak sleeper.

The author proceeds to show by drawings how by giving them a varying cross-section the various forms of steel sleepers now in use may be improved, including the Vautherin, Elberfeld, Prussian State Railways, Rhenish Railway and Austrian Railway patterns. The principle is applicable not only to sleepers for Vignoles rails, but the advantage of the local strengthening is even more apparent when, as in the case of Webb's sleepers as used on the London and North-Western Railway, a number of holes have to be made in the sleeper for the attachment of a chair to carry a bull-head rail; for in order that the rivets may hold for a length of time it is necessary that the plates should have a certain thickness.

There has been much discussion as to the relative merits of the Vignoles and bull-head rails, and German engineers who have been sent to England to report upon English permanent way, and its small cost of maintenance, have sometimes overlooked the fact that it weighs from 400 to 550 lbs. per yard as against 240 to 320 lbs. per yard, the weight of the German line. For the same price as is paid for the English permanent way a line on the German system could be made just as solid and capable of resistance.

It has been objected that metal sleepers are not heavy enough to make a good permanent way. The secret of a good sleeper is, however, not weight alone, but depends also on—

(1) Appropriate form.

(2) A section with sufficient moment of resistance.

(3) A material not easily fractured.

(4) Sufficient bearing area and length.

As to form, the closing of the end of the sleeper deserves special attention. In the early open-ended sleepers the 1 in 20 slope for the bed of the rail tended to drive the ballast out from underneath, while a sloping closed end, as now used by the Netherlands Railway Company, tends to drive the ballast in under the rail.

In order that the punching of the holes for fastenings may not have an injurious effect hard steel is now avoided, and the sleepers are made of mild steel (Bessemer, Thomas or Siemens) capable of resisting a tensile strain of 25.4 to 28.6 tons per square inch, with a minimum contraction of 30 to 40 per cent.

In case of anything leaving the line, also, mild steel is much to be preferred to hard steel for sleepers, as it is less liable to be broken.

Formerly there was anxiety as to the rusting of iron sleepers, but it is now known that this is trifling in the case of sleepers in use, so few railway companies use preventives such as galvanizing, steam oxidation, oxide of lead or tar. Only for the sleepers kept in reserve by the side of the line or for parts of the line where the atmospheric influences are bad (damp tunnels), or for sleepers for transport by sea is it needful to use tar or paint.

After many years of trial the Netherlands State Railway has decided to keep to screw bolts as the means of attachment between the rail and sleeper. In 1865 they had lain ten thousand iron sleepers of a now antiquated design on their main line near Deventer. The rails were fastened by four bolts, 0.42 inch diameter, to each sleeper. For the first time, in 1883, it was necessary to renew two thousand of these forty thousand bolts, and the remaining thirty-eight thousand are still (August, 1885) in use. This shows the bolts 0.86 inch in diameter now used will be satisfactory. The bolt-holes in the sleepers are square except that the corners are slightly rounded.

The beating up of the ballast under steel sleepers must be so done that the middle of the sleeper is filled but not with compact ballast, while for a distance of 12 to 15 inches on each side of the rail the ballast must be well beaten up.

It is also very important that during the first few months after the sleepers are laid, the road should have great and constant attention until the beds become consolidated. The cost of this ought to be considered as part of the cost of laying the road.

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## FLOODING THE SAHARA.

By GEO. W. PLYMPTON.

From "Science."

Much misinformation has of late been spread abroad respecting "the proposed interior sea of Africa," and the public has been misled by inaccurate statements in regard to the magnitude of the enterprise, which, it is assumed, the French people are about to undertake. For these current erroneous impressions the English and American scientific journals are largely to blame. An old theory regarding the Sahara—that it was for the most part below the level of the ocean—has been adopted as though modern surveys had not refuted it; and so the conversion of a material portion of the African continent into a navigable sea is being popularly considered as not only possible, but altogether likely to be accomplished.

A brief consideration of the published results of the recent surveys will be sufficient to convince the reader that the popular estimate of the magnitude of this enterprise is absurdly out of proportion to the greatest possible accomplishment.

This overestimate is not surprising when we consider the character of the references to the scheme which have been made by journals of the best standing. The following paragraph from the foremost among engineering journals may be taken as a sample:

"With reference to the daring French project for flooding the desert of Sahara with what would be virtually a new sea, it may be well to recall the opinion expressed by M. Elisée Réclus, that at one period in the world's history the desert was covered by a sea very similar to the Mediterranean, and that this sea exercised a very great influence upon the temperature of France, as comparatively cold—or, at any rate, cool—winds blew over it, while now the winds which prevail in the great expanse are of a much higher temperature, and are, in fact, sometimes suffocatingly hot. The appearance of the desert seems to support the theory of M. Elisée Réclus, that it was at one time the bed of a sea of considerable extent, of which the great inland African lakes recently discovered are possibly the remains. The present vast extent and configuration of the African continent would also appear to support the conclusion that at one time it comprised a less area of land than it does at present. The serious question which arises, assuming that the theory of M. Elisée Réclus is substantially correct, is, What will be the effect of the creation of a second African sea in the room of that which has disappeared? Would the temperature of France, and possibly even of England, be again reduced? It is a geological theory that in the glacial period of the world's history Great Britain was covered with ice and snow very much as Greenland is at present. Some great influences must clearly have been brought to bear upon France and Great Britain, which rolled the ice over so many hundred miles northward. What was this influence? Was it the large African sea which French enterprise is endeavoring to recreate? If it were, we should say that whatever the French may gain in Africa by the realization of a Saharan Sea would be much more than counterbalanced by what they would lose in France itself."


MEDITERRANEAN
ALGERIA
SAHEL
ARAD
REGION OF DUNES
BIZERTE
Port Farina
Tunis
TUNIS
La Goulette
Utica
PHILIPPEVILLE
BONA
La Calle
Lake Tonara
BEJA
TEBOURSOUK
Testour
Zaghouan
Hammamet
Gulf of Hammamet
CONSTANTINE
Souk Arras
HAKIM
KEF
SOUSSI
SOUSA
Monastir
KAIROWAN
ZIDAS
MEJERI
FRECHICHE
Tebessa
Batna
Mont Aurès
EL DJEM (Amphitheatre)
MTALLIN
Sbeitla
Kasrya
Feriana
HAMMAMA
Diskra
SFAX
NEFTA
Gafsa
MAHADEBA
Gulf of Gabes
Chott Melrhir
Chott Asloudj
Chott Rharsa
DJERID
Nefta
Tozeur
GABES
Chott Djerid
Kebili
Zarzisse
Behina
El Ouad
SOUF
ZID
Donz
El Foonar
GUERGAM
El Biarhotta (Well)
El Aghouan (Well)
Kemada el Gasis
Berrecof
TRIPOLI
PROPOSED INLAND SEA IN ALGERIA.
PROFILE
CHOTT MELRHIR
CHOTT RHARSA
CHOTT
FEJEJ

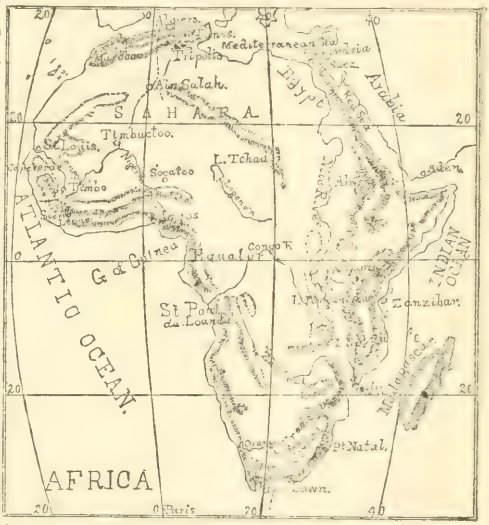
A writer in another journal suggests that all nations interested in the commerce of the Mediterranean may by right protest against the execution of a scheme that would produce a troublesome current through the Straits of Gibraltar. And the same writer, furthermore, adds, "So much water drawn from the present oceans, may, by lessening the depths of the harbors of the world, produce serious and wide-spread inconvenience."

That all such fears are utterly groundless is abundantly shown by the results of the careful surveys made within the last few years. A brief résumé of these results is presented below. The figures are reduced from the metric measures in "Nouvelle geographie universelle," by Réclus, and the maps from "Le génie civil." In both cases the authority quoted is the French engineer, M. Roudaire.

Every one who, as a student, has had to draw the map of Africa, can certainly recall that singular interruption to the otherwise regular coast-line on the extreme northern boundary, where the coast, for a comparatively short distance, has a general north and south trend. This notch marks the north-eastern terminus of the Atlas mountain system. The eastern shore is the eastern boundary of Tunis; and on it, in ancient times, stood Carthage. An indentation at the southern part is called the Gulf of Gabès.

A line extending due west from the shore of this gulf crosses a barren region, of no interest but for the project about which this article is written. It is a region abounding in basin-shaped depressions, containing either shallow salt-marshes, brackish pools, or deposits of salt and gypsum. The more extensive areas are called "chotts." The first of these is the Chott-el-Fedjedj, the eastern end of which is 12 miles from the shore of the gulf, and separated from it by a ridge of drift and limestone whose altitude at the lowest point is 150 feet. The surface of el-Fedjedj is nowhere less than 48 feet above the sea. Toward the west it is contracted in width somewhat by the encroachment of the ridges which bound it on the north and south. Beyond this point, which is about 70 miles from its eastern limit, it widens out, and is known as Chott-el-Djerid. Here the surface is for the most part level, and covered with an incrustation of salt, beneath which, in a few places, are pools of water. The plain of el-Djerid is from 50 to 200 feet above the sea-level. Its width from north to south is about 45 miles.

Near the north-west border of el-Djerid, and separated from it by a ridge whose least altitude is 550 feet, is the Chott Gharsa or Rharsa, whose surface is from 30 to 35 feet below the level of the sea. Gharsa is about 50 miles long and 20 miles wide. Beyond this chott to the west, and separated from it by an insignificant elevation, is a much larger depressed area, known as Chott Melghigh or Melhrie. This is the basin referred




MAP OF AFRICA, SHOWING THE RELATIVE SIZE OF THE PROPOSED INLAND SEAS.

to as the site of the proposed interior sea. The area which, lying below the Mediterranean, can possibly be flooded by it, is represented by the shaded portion on the accompanying maps.* Portions of this area are 100 feet below the sea-level; and the average depth, if flooded, would be 78 feet.

The figures above given exhibit the possible dimensions of the "flooded Sahara." The united areas of the two chotts over which the sea would flow is, by Roudaire's measurements, about 3,100 square miles, less than half the area of Lake Ontario.

* The scale of the larger map is about 58 miles to the inch.

Throughout the remainder of the Great Desert the elevation is considerable. Competent authorities estimate the average height at 1,100 feet. Dr. Lenz found, in traveling over many hundred miles of the western portion of the Sahara, no point of less altitude than 470 feet above the sea.

The fact that marine deposits are found in many parts of this area is, of course, a fact of no significance in this connection. The skeleton of a whale found in one of the highest cuttings of the Vermont Central Railway is not regarded as an evidence that the Green Mountains could now be submerged by the waters of the ocean.

The whale probably stranded there during what geologists term the "Champlain epoch," since which time the surface has slowly risen. The hypothesis that at least eighty thousand years have elapsed since this epoch is believed by most geologists to be well founded. Explorations across the African desert justify the belief that the marine deposits found there are not less ancient than those of the Champlain period.

To flood such a section with the sea, either the next great subsidence must be patiently awaited, or else an extensive system of pumping must be resorted to. The realization of the scheme of submergence (to accord with the popular estimate of it), by either of these plans, may be regarded as equally remote.

The project of flooding the Sahara to the utmost practicable limit can hardly be called a great one. It is safe to say, that if executed, which is doubtful, it will not sensibly affect the climate of southern Europe. It will not create dangerous currents at Gibraltar, nor inconvenience seaports in any part of the world.

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## ELIMINATION OF ERRORS IN FIELD WORK.

By WM. BOUTON, Member of the Engineers' Club of St. Louis.

Journal of the Association of Engineering Societies.

Accuracy is a relative term. "We speak of a thing as accurate with reference to the care bestowed upon its execution, and the increased correctness to be expected therefrom" (Webster's Synonyms). It would not be accuracy but confiscation to expend the same amount of painstaking labor in surveying land worth one dollar and a quarter an acre that would be essential in surveying town lots, where the walls of valuable buildings abut with precision upon the property lines. The purpose of the work determines the method which should be used, and the amount of human frailty which may receive the award "well done." Old surveys are often retraced by the methods originally used, and are found accurate, *i.e.*, without mistake, and with a care adequate to the use for which the property is fitted. When the use changes, and with it the method of surveying, it is probable that every line will have a revised and corrected length, every angle a different observed value. A surveyor engaged in such work is trying to find out how much the ground has grown since it was measured last. Mr. Culley (see the *Journal* of September, 1884), makes an earnest appeal for the transit and steel tape for farm surveying. When the course of the survey strikes into ground that is covered with briars and hazel brush, honey locust and poison oak, grape vines and other vines too numerous to mention, with weeds ten feet high wherever they can get breathing room, I confess that for my part I prefer the compass and chain, and consider that method entirely adequate until the land can be put to some better use; but if the land is well cultivated and the fence rows are clean, it is practicable to use the transit and tape without much extra cost and with very much more satisfactory results. It is generally true that the earliest application of more accurate methods finds, before the work can proceed, more rough places to be made smooth, than crooked places to be made straight. The best work cannot be done under such circumstances; while human nature

stops short of absolute perfection, the quality of the work, of those who are competent and careful, will be affected by conditions under which their work is done. To him who makes the elimination of error from his own work a labor of love, or a matter of professional pride, it will soon be plain that every kind of error, which can in the nature of the case possibly exist, will some time be found, that the simplest kinds of work involve many possibilities of error, and will further find that every check introduced into the work in order to prevent error, brings in its train new possibilities of error.

If the problem is to retrace an old survey, having the original notes, a comparison of the resurvey with the original will probably show errors in one or the other, which may be classified as follows:

1. Errors due to difference of method used.

2. Errors due to the extent of the work and to the passage of obstacles.

3. Errors in the work or record due to the incompetence or carelessness of either surveyor.

These observed errors are the algebraic difference of errors, kind for kind, of the two surveys. The true values are not to be reached by a division of the observed errors, nor by the assumption that they all belong to the older survey. Approximation to the truth is to be sought for in the increased care given to resurveys.

When a survey takes the form of a subdivision with a recorded plat, and deeds are made referring to the plat of record, the number of possible errors is very much increased. In making a subdivision no pains should be spared (here virtue brings its own reward, if not to the surveyor, at least to the community); the plat should be mathematically consistent, and should correctly show how the subdivision stands related to original property lines; monuments marking the more important points of subdivision should be accurately placed upon the ground. Angles as well as lines and distances are an essential part of a workmanlike plat. The ideal subdivision is seldom seen. On the other hand, the number of hairs in a man's head would all be needed, if he should attempt to keep tally with them in how many ways a subdivision, or its recorded plat, or the corner stones may be wrong.

Next comes the conveyancing built upon this foundation. An ingenious notary can make things lively for a surveyor; the half was never told.

The field notes purport to give an account of how the corners have been perpetuated, what marks now exist and how the subdivision has been verified by resurvey. If they fail to give this information, that failure is often a source of error.

The place where most of the errors so far noted should be corrected is in the office, but the place where they will materialize, if not corrected, is in the field. They form the vast majority of the reasons why "two surveyors can never agree." A judiciously arranged and thoroughly equipped office is an essential precedent to correct field work, and makes many things possible which, without it, are impossible.

There are surveyors who say, "I don't go into any such questions. I survey what is ordered. If a man brings his deed to me, and says, 'I want this lot surveyed,' and that deed contains a description which can be located, I follow it; if it contains other words and phrases which presumably mean something, but what they mean is uncertain, I ignore them—all that belongs to the investigator of titles."

Suppose that this statement is made to the owner of the lot, and he says, "Yes; I had the title investigated, here is my abstract." You take it, and read the description in the deed, possibly with the puzzling phrases omitted, and a certificate like this: "I have examined the public records of X county, and the indexes thereto attached, and find the title to the above-described lot fully vested in John Smith; taxes paid; judgments, none," you don't feel that you have learned much; but if you inquire further, the investigator will tell you something like this: "The *chain of title* is complete from the original owner to the present. The conveyances are in due form." "But," you ask, "what is the force of this call for boundary?" or this: "And being the same property conveyed by deed of Brown to Jones?" He may reply, "The wording of that deed from Brown was a little different from that of the present deed; but it is not such a difference that

I can sit here in my office, and, looking at the two papers, say that they must mean different things; that is a *question for surveyors.* As to that 'boundary,' I was investigating Smith's title, not his neighbor's." Between such investigators and such surveyors and notaries, who are willing to add or omit a word or phrase in order to make the meaning as they understand it plain, there is many a stitch dropped. Neither can keep closely to what he is pleased to term his own business and give a final result free from mistakes. If there be a mistake in some such way caused, whose fault is it that the location is wrong? Generally, I think, the surveyor's. He is employed to correctly interpret the meaning of that deed by marks upon the ground. It is his business to get, and require pay for getting, in some way the information necessary in order to do the work. Interpretation presupposes understanding; it will not do, while a part of the deed is in doubt, to interpret what is plain and say, "This is all." Some State law-makers need to learn this lesson.

"If the work so far described has been well done, the field work is next in order. The location of a line is the accurate determination and marking of its origin, direction and length. There is a trite saying, "If surveyors could only agree on what they should measure from, the rest of the differences would be of little account." While there is something to be said as to other differences, after this branch of the subject is finished, I feel compelled to admit that there is a deal of force in this view. It involves the perpetuation of lines by all the methods known to the craft, and the verification to-day of that which survives from the past. In a majority of instances in this city the deeds recite that the property sold is a part of —— Subdivision, as per plat of record. The recorded plat usually does not show how the lines were marked; does not even show that they were ever marked at all. Nevertheless it is fairly probable that stones or other monuments have been set. What is now the proper thing to do? Shall I agree with Pope that, "whatever is, is right," and take unquestioning that which first comes to hand and make from it the required location? If so, my neighbor who has an office across the street, may with equal right measure from the other end of the block and certify my survey wrong. Monuments derive their authority, not from the fact that they exist, but from the fact that they conform with reasonable accuracy to the recorded plat. To say that the location of the subdivision logically precedes the location of lots within it, is but another way of saying the same thing. It is the surveyor's business, not to assume, but to know with reasonable, or at least with all attainable certainty, that the monuments found correspond to the subdivision. Having once verified carefully the position of corner stones, or whatever else approximates permanence, that position is for the future a matter of knowledge. But the *permanence* of all marks whose position is essential to the survey must whenever used be tested before a location is made.

Although much field work has been implied in what has been already said, the discussion of methods of measuring has been left until more important things were disposed of; no care in determining the length of a line can make that survey correct which begins in the wrong place and ends nowhere.

Considered as affecting the result, errors are plus or minus. Some of the sources of error which affect every piece of work are as likely to produce plus as minus errors, and will, in fact, produce both plus and minus errors in the same piece of work, *e. g.*, inaccuracies in observing the point of a plumb, or its vibration in a still day. The theory of probability shows that if the number of trials is made sufficiently large the number of times when each possible event will occur will be in precise proportion to the probability of that event. If the errors due to any source are as likely to be plus as minus, the relative resultant error will become less than any assignable limit, as the extent of the work approximates infinity. Experience will enable the surveyor to fix upon the value of the maximum error in his own work for a short distance, say 100 feet. The maximum possible error is a simple multiple of this, and it is something approximating this maximum occurring at improbable and unexpected times that plagues and costs reputation at least. I have found no better way of eliminating this possibility

than by measuring and running general lines, such as boundaries of the larger tracts, then cutting up the area by intersecting lines and tying up every survey at both ends.

Other sources of error are in their nature not compensating but cumulative. The ideal surveyor applies such a correction as to make every cumulative error compensating. In the free-hand work of the surveyor, any cumulative error, if platted in terms of the distance measured, would show a wavy line; a correction of its average value would leave a compensating error—a sort of second differential. I proceed to consider some cases.

Within the last twenty years the old method of using wooden rods when accurate measurement was desired has been with great advantage replaced by the use of the steel tape. The surveyor professes to give the horizontal distances between points noted. A man measuring with a tape never measures a horizontal distance. What he does measure is a succession of catenary curves. Men who ought to know better have suggested that this may be all very true, but it don't amount to much anyhow. I suggest the following as worthy of notice. Any curve is longer than its chord; it is also longer than the sum of the two chords which join its ends with its middle point. If the tape used is fifty feet long, and the sag at the center is one-half a foot, the short chords diverge from the long chords at the rate of two feet in one hundred. A moment's inspection of a table of cosines will show that the sum of the short chords exceeds that of the long chords by more than one foot in a mile. I consider that this approximate error from one source is greater than the sum of all the errors which a reasonable man surveying city lots should admit into his work. The case demands attention.

The following table I have found convenient in my own work, and submit for what it is worth. Taking the condition that the tape is of uniform section and carries no load except its own weight, I use the following nomenclature:

H = horizontal tension.

$w$ = weight of unit of length.

W = weight of tape.

$e$ = base of Naperian logarithms.

$s$ = length of curve from origin.

$l$ = length of tape.

$x$ and $y$ = horizontal and vertical co-ordinates, origin at lowest point.

Then $y = \frac{H}{2w}\left(e^{\frac{wx}{H}} + e^{-\frac{wx}{H}} - 2\right)$,

and $S = \frac{H}{2w}\left(e^{\frac{wx}{H}} - e^{-\frac{wx}{H}}\right)$.

Observe that if $\frac{H}{2w}$ is constant, $y$ and $s$ constant, for $x = \frac{1}{2}l$.

For assumed values of this ratio varying between sufficiently wide limits, the effects of the sag and of the corresponding pull are tabulated. When the sag is

$x$ = 25 Feet. Tape 50 Feet Long.

| Sag. | | | Pull. | | Resultant ±. | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Error in 50 Feet. | | Error in 1,000 Feet. | |
| $\frac{H}{w}$. | $y$. | Excess of Curve. −Error. | $\frac{H}{W}$ | Elongat'n +Error. | − | + | − | + |
| | Feet. | Feet. | | Feet. | Feet. | Feet. | Feet. | |
| 400 | 0.78 | 0 0326 | 8 | 0.0025 | 0.0301 | — | 0.602 | — |
| 500 | 0.63 | 0.0200 | 10 | 0.0031 | 0.0169 | — | 0.338 | — |
| 600 | 0.52 | 0.0140 | 12 | 0.0037 | 0.0103 | — | 0.206 | — |
| 700 | 0.45 | 0.0098 | 14 | 0.0043 | 0.0055 | — | 0.110 | — |
| 800 | 0.39 | 0.0071 | 16 | 0.0050 | 0.0021 | — | 0.042 | — |
| 900 | 0.35 | 0.0055 | 18 | 0.0056 | — | 0.0001 | — | 0.002 |
| 1,000 | 0.31 | 0.0045 | 20 | 0.0062 | — | 0.0017 | — | 0.034 |
| 1,100 | 0.28 | 0.0040 | 22 | 0.0068 | — | 0.0028 | — | 0.056 |
| 1,200 | 0.26 | 0.0037 | 24 | 0.0075 | — | 0.0038 | — | 0.076 |
| | | | | | | | — | |

$x$=50 Feet. Tape 100 Feet Long.

| Sag. | | | Pull. | | Resultant ±. | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Error in 100 Feet. | | Error in 1,000 Feet. | |
| $\frac{H}{w}$. | $y$. | Excess of Curve. −Error. | $\frac{H}{W}$. | Elongat'n +Error. | − | + | − | + |
| | Feet. | Feet. | | Feet. | Feet. | Feet. | Feet. | Feet. |
| 800 | 1.56 | 0.0652 | 8 | 0.0099 | 0.0553 | — | 0.553 | — |
| 900 | 1.39 | 0.0509 | 9 | 0.0112 | 0.0397 | — | 0.397 | — |
| 1,000 | 1.25 | 0.0400 | 10 | 0.0124 | 0.0276 | — | 0.276 | — |
| 1,100 | 1.14 | 0.0334 | 11 | 0.0137 | 0.0197 | — | 0.197 | — |
| 1,200 | 1.04 | 0.0279 | 12 | 0.0149 | 0.0130 | — | 0.130 | — |
| 1,300 | 0.96 | 0.0234 | 13 | 0.0161 | 0.0073 | — | 0.073 | — |
| 1,400 | 0.89 | 0.0196 | 14 | 0.0174 | 0.0022 | — | 0.022 | — |
| 1,500 | 0.83 | 0 0166 | 15 | 0.0186 | — | 0.0020 | — | 0.020 |
| 1,600 | 0.78 | 0.0142 | 16 | 0 0199 | — | 0 0057 | — | 0.057 |
| 1,800 | 0.70 | 0.0109 | 18 | 0.0223 | — | 0.0114 | — | 0.114 |
| 2,000 | 0 62 | 0.0090 | 20 | 0.0249 | — | 0.0159 | — | 0.159 |
| 2,400 | 0.52 | 0.0074 | 24 | 0.0298 | — | 0.0224 | — | 0.224 |

observed the errors shown are correct, the pull need not be observed, and the tape may be heavy or light. If an engineer prefers to estimate or measure his pull rather than his sag, let him divide his pull by the weight of his tape and seek the quotient in the fourth column and the corresponding error in the sixth or seventh. I add the second part of the table for such as prefer a tape 100 feet long.

In the formula elongation $= \frac{P\,l}{E k'} \frac{P}{k}$ is a multiple of $\frac{H}{w}$ in the first column of the table. Hence the elongation varies as $\frac{H}{w}$. I have used $w$=3.4 $k$ for tempered steel. A change in E, modulus of elasticity, would change the fifth column and all derived from it.

I do not think there can be a difference in tempered steel reduced to so small a section as a tape which will be of sufficient importance to be taken account of in surveyors' work. Professor Johnson, of our club, made, in 1881, for the United States, a series of experiments upon a Chesterman 300 feet long; he found E=27,400,000. I have used his coefficient. I see Mr. Culley uses 29,000,000, but cannot find any reason to suppose it has better authority. It would appear from the table that it is practicable to pull such an amount that no correction need be applied for these errors. Experience will show, however, that, if the habitual pull is right for a perfect calm, the slightest wind will carry out the center of the tape to fully one-half a foot sag, without being sufficient to suggest the necessity for increasing the pull in order to reduce the sag.

A second reason why surveyors do not measure horizontal distances is that the ends of the tape are not kept level. If a man says "I can do it," watch him closely, for when he succeeds it will be a mistake. If he says "I can come pretty near it," give him credit for understanding the situation and watch him too. There is a difference of ability to judge, but at some point every person would recognize such an error. In this case we have the joint judgment of at least two men presumably somewhat experienced.

The limit of their error will be approximately uniform for like conditions; probably will not exceed two per cent. of the length of the tape. We may suppose that no error in judging the level exceeds two per cent., and assuming a probable distribution of errors within that limit calculate the probable correction, but the result is too small to account for the facts. A surveyor of any experience knows that somehow or other this correction must sometimes amount to con-

siderable. On lines where appearances are deceiving, it is customary, when there is a difference of opinion, to test the matter by plumbing a different height, and correcting the pin, if an error is apparent. Now this method of correction is not applicable to errors of inclination, which are smaller than two per cent., and some which are larger than that will slip through. On some lines this check is necessary every time for a large part of the distance. On such lines the head is no longer level; the apparent horizontal differs from the truth, and the probable range of error instead of being equally each side of the horizontal, is all one side, and may be at its limit nearly five per cent. The part exceeding two per cent. may be very nearly all eliminated by the method noted above. I conclude that there is *always* an error due to the fact that the tape is not horizontal, and this is always a minus error. A constant correction for it and for the resultant between sag and pull should be determined by the surveyor for his "team," and applied to sticking of the pin. A further minus correction is due this cause on difficult lines, before it should be called a mistake; at its extreme limit I place it at two-tenths of a foot in one thousand feet —the correction due to an inclination of two per cent. This further correction should never be applied to *graded* lines, for there such an error is inexcusable.

"Were it not for variations due to temperature," Mr. Culley says, "All lines, both long and short, within the scope of the land surveyor, could be measured exactly." The idea of dating a survey in order to be able to judge of the probable error due to this cause, which he suggests farther on, may do in Cleveland; but in a climate which boasts of 80° F. in January, and 60° F. in July, with a wide range of temperature in any month, this method of eliminating the error is fallacious. The plus and minus maximum errors due to this cause are very large; but the easiest in the whole list to manage. I attach a thermometer to my transit so as to carry it conveniently, observe the temperature in the sun or in the shade, according to the average condition of the line, and make the correction then and there.

The standards furnished by the Government are rods of steel correct at 60° F., or as marked. Using these, a rod of steel as long as the tape used should be marked with the standard length at 60° F. This standard, for obvious reasons, should be sheltered from the sun, wind and rain. If an office floor is long enough, it will furnish a convenient place for fixing it. The center should be held firmly, and the ends be so fastened that they may expand freely, but cannot be bent or sprung out of place. The marking should be done after it is in place. A tape tested on such a standard is correct at 60° F., whatever may be the temperature when the test takes place, provided that the tape be brought to the *same temperature* as the rod before the test is made. All measurements should be made with the tape at its tested length, and the correction applied to the whole distance measured. Some tapes are made so as to apply the correction to the tape. I have tried both ways, and don't want any adjustable tape in my work. A thermometer is equally necessary, and one more loose end is to be watched with no corresponding advantage.

I have found this table useful on a fly leaf of my field book:

—Errors.

| Deg. F. | 100′ | 200′ | 300′ | 400′ | 500′ | 600′ | 700′ | 800′ | 900′ |
|---|---|---|---|---|---|---|---|---|---|
| | Feet. | Feet. | Feet. | Feet. | Feet. | Feet. | Feet. | Feet. | Feet. |
| 0 | 0.042 | 0.084 | 0.126 | 0.168 | 0.210 | 0.252 | 0.294 | 0.336 | .378 |
| 10 | .035 | .070 | .105 | .140 | .175 | .210 | .245 | .280 | .315 |
| 20 | .028 | .056 | .084 | .112 | .140 | .168 | .196 | .224 | .252 |
| 30 | .021 | .042 | .063 | .084 | .105 | .126 | .147 | .168 | .189 |
| 40 | .014 | .028 | .042 | .056 | .070 | .084 | .098 | .112 | .126 |
| 50 | .007 | .014 | .021 | .028 | .035 | .042 | .049 | .056 | .063 |

| | +Errors. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 70 | .007 | .014 | .021 | .028 | .035 | .042 | .049 | .056 | .063 |
| 80 | .014 | .028 | .042 | .056 | .070 | .084 | .098 | .112 | .126 |
| 90 | .021 | .042 | .063 | .084 | .105 | .126 | .147 | .168 | .189 |
| 100 | .028 | .056 | .084 | .112 | .140 | .168 | .196 | .224 | .252 |
| 110 | .035 | .070 | .105 | .140 | .175 | .210 | .245 | .280 | .315 |
| 120 | .042 | .084 | .126 | .168 | .210 | .252 | .294 | .336 | .378 |

There is nothing new in it, but it is better to do a simple thing right once for all than to be doing it over and over again for all time.

The force of the wind upsets all these calculations. Our catenary curve that was a function of $x$ and $y$ is now a function of $x$, $y$ and $z$. The plumb ceases to point to the center of the earth. Its average position is misleading—is the result of a composition of forces. These effects can be mitigated to some extent by holding the center of the tape to its place in line, by shielding the plumb and increasing the pull; but such work is always unsatisfactory. The only way to eliminate this source of manifold errors is to cease from any piece of work when the wind is so high that it cannot be done as it should be done. There are estimates, topography, etc., which do not require a high degree of precision and can be done when other work cannot.

Subdivision work, where it is proposed to to build brick walls to property lines, showing errors in closing or subdivision of 1 in 5,000, should doubtless be retraced. The average error of re-surveys, built on such a basis, need not exceed 1 in 20,000. The maximum error can then be kept within manageable limits.

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## SOME POINTS ABOUT MODERN WAR SHIPS

By LIEUT. B. A. FISKE, U.S.N.

The best rough measure of the value of a modern war ship is the weight of water she displaces, for this equals the weight of the ship and her contents, and the greater it is the larger her hull can be, the thicker her armor, the more powerful her engines, the heavier her guns, and the greater her coal and ammunition capacity.

A perfect war ship would be one able to resist any projectile or torpedo and to pierce any armor made, and at the same time to throw a greater weight of metal per minute, to turn more rapidly, and to steam faster and further than any other.

Ability to resist any projectile or torpedo would necessitate great thickness of armor and a heavy inner bottom; ability to pierce any armor would require very large guns; ability to throw a greater weight of metal per minute than any foreign war ship would render necessary a considerable number of guns, and these would require a considerable space to be protected, which means a considerable extent of armor.

We can see at a glance that the weight of guns and armor alone would be enormous, and that, in consequence, the ship would be immense, since she must be, not only as large as a volume of water of equal weight, but larger, in order that she may possess sufficient reserve buoyancy to float her when a sea comes on board, or when a water-tight compartment fills after a torpedo explosion or a collision. But the ship must be large enough to float, in addition, her machinery and coal, and these would be very heavy, since the boilers and engines must be very powerful in order to secure the necessary speed, and must have an enormous supply of coal at hand in order to steam the necessary distance.

Clearly, a perfect war ship would be an exceedingly heavy and expensive one. An English naval architect in a recent lecture before the Royal Naval College,

stated that a war ship, to be even approximately perfect, would weigh about 25,000 tons, and cost, at least, £2,000,000!

Since perfection cannot, at any practicable cost, be attained in any one war ship, the only thing to do is to design a number for different purposes, seeking in each certain excellencies, and resigning others. In a heavily armored ship, in which power of offence and defence must be very great, the weight allowed must be expended principally in guns and armor, so that great speed and coal endurance have to be abandoned. In a cruiser, on the other hand, speed and coal endurance are essential, so that armor and heavy guns must be resigned; while in a gunboat heavy guns and great speed must be secured, and armor and coal endurance sacrificed.

Furthermore, speed is comparatively an easy thing to get in a ship, if we are at liberty to make her as long, as narrow, and as deep as we please, and to place the boilers, engines and steam-pipes in convenient positions. But a long ship will not turn so quickly as a shorter one, yet handiness is almost as important in a war ship as speed; a long ship cannot have so thick armor as a shorter one carrying an equal weight of armor, and she is easier to hit. To make a war ship deep forces on her the naval disadvantage of great draught, which prevents her from entering some harbors and from chasing vessels near some coasts; and boilers, engines and steam-pipes have to be crowded below the water line to protect them from projectiles. Is it a matter for wonder, then, that war ships are not so fast as some passenger steamers whose requirements are so simple?

It is sometimes urged that war ships should carry a great deal of sail, in order to be able to stay a long time at sea without going into port for coal. But masts and spars are very heavy; they fall on deck when struck in action, and kill men, and they present such resistance to the air that they decrease the speed when a ship is fighting under steam alone—which is the only way in which a ship can fight. Moreover, if a war ship should be caught under sail by a hostile war ship under steam alone, she would simply be in the position of a ship unprepared meeting a ship thoroughly prepared to fight; and while she had her men aloft furling sail and "clearing ship for action," the other could be knocking holes in her hull with heavyy guns, and killing the men aloft with Hotchkiss and Gatling machine guns.

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## SOME OFTEN NEGLECTED DUTIES OF THE ENGINEER.

By FRANCIS COLLINGWOOD, Am. Soc. C. E.

An Address before the Alumni of Rensselaer Polytechnic Institute.

In a recent address before the Institution of Mining Engineers, the subject of ethics, as bearing upon engineering practice, was treated with some fullness by the retiring president, Mr. Baylis. It is not my intention to repeat what he has so well said, or to take up the more obvious duties which are so often brought forward in addresses at the commencement season. Such addresses usually treat of those qualities which form the foundation of the character of every really successful engineer, and more especially of the necessity for that absolute honesty of purpose in every relation he holds, whether as designer, as supervisor, or as arbitrator, which alone can lead to the thoroughness of work, and which at once places him on his guard against any dishonest approach, however it may be disguised. Out of this one requirement spring all the *ordinary* duties of the profession; but passing these by we come to others more recondite, growing out of the relations of the engineer to the profession and to the world of science, and which seem more appropriate for consideration in addressing a society among whose members are men of large professional experience. These latter duties are none the less important, but in the hurry of active

life, they are too often overlooked or but imperfectly performed, and since every dereliction of duty is sure to react to our detriment, it the part of wisdom to guard watchfully against such in every direction.

Entering, then, upon our subject, and proceeding from the lesser to the greater, let us consider first the relations of the chief engineer of an important work to the members of his staff. As a matter of course he expects absolute loyalty on the part of all those under him, and any disloyalty would probably end in the prompt dismissal of the offender. How shall such loyalty be obtained? Shall it be the result of fear, or shall it be bred of mutual regard and confidence? In other words, is the duty *all* on the part of the subordinate, or is there a reciprocal obligation implied on the part of the chief? If the latter question be affirmatively answered, as it must be, let us proceed to state clearly what the obligation is. Here we should remember that the most eminent engineers have all been subordinates, and have had the help of others by which to rise. As an inevitable corollary upon this, it follows that the chief owes it to all in his employ to help them freely in their difficulties, and to be readily approachable. By thus doing he will make them stronger men professionally and help forward his own success. Our first duty, then, may be defined as that of politeness, affability, and a personal regard for subordinates. Mr. H. H. Richardson, of Boston the well-known architect, recently deceased, furnished a prominent example of one who nobly fulfilled this duty. In a notice of his life work, the *Sanitary Engineer* writes as follows:

"Nor less delightful than this office in the country was Mr. Richardson's relation to the draughtsmen he employed. Only those who have had the privilege of working under him can have much idea of the generous interest he took in their welfare and artistic progress, encouraging them and advising them in their studies, and ever ready to listen to intelligent suggestions, treating his men as personal friends rather than employes. Often he would invite a number of his older pupils to evening reunions, where he would talk over with them matters relating to their art. His valuable library and collection of photographs was always accessible to his draughtsmen, and he encouraged their constant reference to them. Few men have such power as he had of filling others with his own enthusiasm."

There is a second way in which the chief can help those under him, but to which selfishness often blinds his eyes.

It frequently happens in the progress of a work that the one coming in immediate contact with some of the many problems involved will bring out a solution or work up a design having real merit. The credit for such design does not belong to the chief, and, as a matter of simple justice, he should, in making up his reports, give full credit to the designer; yet, in many cases this is not done at all, and the assistant is mentioned in merely general terms and with no reference to his special work. This is not the way to obtain whole-hearted service; a chief engineer can *always* afford to be generous to his helpers. A full acknowledgment of all good work, no matter by whom done, in nowise detracts from his own standing; on the contrary, the world will think the better of him for it. The work is always known afterwards as that of the chief, and if he adds generosity to his other qualities, he will but stand the higher in the estimation of all thinking men. It is said that one great reason for the popularity of General Grant was, his generous treatment of all those under him.

There is yet another duty of the chief which has much to do with a hearty, loyal helpfulness on the part of subordinates. In the inception and progress of a work, it is he who in a great measure determines the respective salaries to be paid to the other members of his staff. The vicious doctrine that no more will be paid than the market will command, with no regard for the cost of living or for the character of the services rendered, too often prevails, and many men seem to think that if *they* are insured a good salary, it is laudable to cut the salaries of all below them down to the lowest attainable limit. It is only necessary to carry this doctrine to its ultimate conclusion to prove that it is both unjust and unwise. If we want a horse to do his fullest work we do not begin by scanting him in his food, but we give him full

provender and the best of care. Are men so different that we can expect them to do their best when they are but half paid for their labors? Is there not sure to be in their minds a rankling sense of injustice? If an assistant so paid be too honest to slight his work, he will still be preoccuppied by thoughts of "how to make both ends meet" in his expenses, or how to be able to meet just debts, possibly those incurred in obtaining the education which has fitted him for the very thing he is doing, and, as we all know, a preoccupied mind is not fitted for deep or consecutive thought on any subject. The chief should therefore insist at the outset upon full compensation for all services rendered, and should be the first to recognize good and faithful work, by asking for such increase in salary as may be consistent with its value. A man who lets neither time, study, labor, nor expense interfere with his attention to his duties, is certainly worth more than one who works always by the clock (trades unions to the contrary, notwithstanding); and a worthy man should not be obliged to ask for that which is rightly his due.

In immediate connection with the subject of organization of a staff arises that of a proper recognition of the relative position of subordinates; by this is meant the military idea that orders shall be issued and reports received always through those next in rank, and not, as is too often done, with an entire disregard of precedence or system. An engineer has a right to suppose that each one in his place is attending to his duties, and to pass over the one next below him and give an order to a minor, implies a lack of confidence in the first, is likely to cause insubordination in the second, and is sure, eventually, to introduce confusion and ill-feeling in the staff. Having placed a man in position he should be held stricty accountable for all work entrusted to him, and if found unfaithful he should be removed; but to pass him by and ignore him, whether by attempting to do the work personally, or by assigning it to others, is an evidence of weakness, and is doing one wrong to mend another.

Such abuse of good management is, however, often committed where no *fault* is attributed, in which case it shows a lack of sound ideas as to administrative methods, and is still to be unqualifiedly condemned. Not only does it introduce discord into the service, but in just so far as a man misdirects the labors of those under him and relieves them of their due share of responsibility, does he injure his own efficiency and make his own labors heavier. Here it may not be amiss to quote with proper reservation the advice that has been given engineers to "never do yourself what you can get others to do for you." In a recent obituary notice of a prominent English engineer the following sentence appropriate to the case in point occurs: "The confidence reposed by Mr. Leather in his staff, and the freedom with which its members were thus enabled to grapple with the many sudden emergencies inseparable from sea-works, were also important factors of his success in these undertakings."

It not unfrequently happens that boards of direction and other employers show a lack of this confidence in their chief engineer, and are guilty of the gross impropriety of attempting to give personal directions to assistants, or of receiving reports from them.

The practice cannot be too strongly reprehended. It is an axiom in physics that two bodies cannot occupy the same place at the same time, and it is no less true that two *persons* cannot attend to one and the same set of duties at once. Confusion is inevitable. "Dual control" is bound to be a failure wherever undertaken.

The subject of reciprocity of duties between the employer and employed (or, as a special case, between the engineer and his assistants) is one that is assuming greater prominence now than ever before in the world's history. Men are slowly learning that the rule of selfishness is inevitably and always *misrule*, and that in the complex relationships of our modern civilization, a wrong done to one class is bound in some way to react on all other classes. Heretofore the wealthy and powerful have been the oppressors, but now the laboring man has learned the lesson so well that he takes delight in entering into a *worse* bondage, in order that, by the might of numbers, he may inflict loss on those whom he conceives to be his enemies. It is evident

that peace and industrial harmony can be again established only on the higher principles of confidence, co-operation, mutual helpfulness, and good will; in other words, on the golden rule of doing as you would be done by. As has been recently so eloquently said by Bishop Potter: "When capitalists and employers of labor have forever dismissed the fallacy, which may be true enough in the domain of political economy, but is essentially false in the domain of religion, that labor and the laborer are alike a commodity, to be bought and sold, employed or dismissed, paid or underpaid, as the market shall decree; when the interest of workman and master shall have been owned by both as one, and the share of the laboring man shall be something more than a mere wage; when the principle of joint interest in what is produced of all the brains and hands that go to produce it is wisely and generously recognized; when the well-being of our fellow men, their homes and food, their pleasures, and their higher moral and spiritual necessities, shall be seen to be matters concerning which we may not dare to say, 'Am I my brother's keeper?' then, but not till then, may we hope those grave social divisions concerning which there need be among us all, as with Israel of old, 'great searchings of heart,'" may cease. But let us return from this episode.

We have thus far discussed what might be called the *family* relationships of the engineer, and more particularly those reaching downward, the duty of each man to lend a helping hand to all below him on a work, thus insuring the highest efficiency of the staff, and doing incidentally a still better thing, helping all to be stronger and more useful men. There is, however, a larger company, of which every engineer forms an integral part and to which he owes certain duties —viz., the profession as a whole; and to this I would next direct your attention.

Here, as in the engineering family, the golden rule should equally guide our actions. Perhaps one of the first ways in which this rule is violated is in passing judgment upon the works of others, in the way of fault-finding and belittling them, picking flaws, making small criticisms of design or methods, etc.

Does any engineer imagine he raises himself in the opinion of others by so doing, or in any way advances his own prospects of success? It cannot be; the world is, on the whole, fair in its estimate of man; it recognizes and appreciates the generous everywhere, and is just as sure to condemn the opposite. Criticism for the purpose of suggesting improvement is a good thing, but criticism for any other purpose is unworthy a true man. The best of men make mistakes, and are made stronger and better by them, and they suffer quite enough mortification from self-condemnation without the animadversion of men frequently of less calibre or purity of purpose. It has been laid down as a rule that the man who has never made a mistake must have had so limited an experience in work that he is not a safe man to trust.

But the subject of professional honor and generosity leads us to a *second* thought—we are bidden on Divine authority to look upon "the things of others," as well as our own, and this will lead us to hold to a high standard in the matter of engagements.

It is, of course, unprofessional, as well as ungentlemanly, to do anything to undermine another for the purpose of supplanting him; but I think we may go a step *further*, and say, where a man has been wrongfully discharged because he would not be made a tool of, either in the way of deceiving the public by doctored reports, by winking at dishonesty in whatever form, or for any other disreputable purpose, we may, indeed we *should*, refuse to accept such position, and so uphold our brother in his protest. As a matter of right, also, an offer should not be entertained for the position filled by another, unless his resignation has already been announced. In other words, if the profession is ever to assume its true dignity as a profession, we must never on our part do aught to bring it into discredit, and we should resent the idea that is held by many, that engineers are tools, or a commodity to be bought and sold, and are entitled to no more consideration than a man who is hired by the day.

The matter of engaging engineers has latterly taken a new phase, which puts this mercantile view in a still stronger light. It is nothing less than asking en-

gineers to bid against each other, for employment. I think I speak the voice of the Rensselaer Society of Engineers, and of the best engineers generally, when I say that they will not *knowingly* enter into such competition. A doctor or a lawyer who would condescend to thus act would be justly considered as unworthy of confidence, and why not an engineer, whose position is eminently a confidential one? A large Western city recently sent letters to a number of the most prominent engineers of established reputation, and whose works were well known, asking them to send a history of their professional experience and of their qualifications to do a certain work, saying that their names had been mentioned in connection with it as engineer. An alderman, not an engineer, was also sent to visit each man, and report. I happen to know at least *one* veteran engineer replied that his work had been before the public for about fifty years, and if *it* did not speak for him, *he* could not speak for himself. Is it too much to say that we owe it not only to ourselves, but to the profession, to make a strong protest against all such indignities? Has it come to this that a well-earned reputation for honesty, thoroughness of work, and ability as an engineer, shall all pass for nothing, and that a man must furnish his autobiography every time he enters a new engagement? Some of the very best men are noted for their modesty, and such a rule once established would result only in advancing those whose chief acquirement is playing a solo on a well-known instrument made usually of brass.

The old times when a man who could measure a ten-acre lot was called an engineer have nearly passed away (we cannot say entirely), and we now have as engineers a body of trained men, with keen intellects, who have taken pains to fit themselves in the most thorough manner for the conduct of work. The responsibilities they are called upon to assume are *many times* those assumed by any other profession, whether we contemplate them as they affect human life and happiness, or in the financial aspect alone; and shall we allow ourselves to be viewed in the light of mere laborers, and nothing more, on the rule of "so much work, so much pay?" I am sure you will all say no to this—emphatically, no; but we can rise no higher so long as we remain a mere mass of units, with no cohesion, each striving to get ahead of others, with no care for the hindmost. We must cultivate an *esprit de corps*, by which we shall come to feel that if one suffers all suffer, by which the world shall know that we do not work merely for hire, and by which we shall make ourselves felt as fully entitled to recognition as professional men, and to be treated accordingly. Nevertheless, it is true that we must live by our profession, and unless we set a proper financial value upon our services others will not do it for us. It is the duty of every engineer to make his charges to bear a reasonable proportion to the value and importance of the service rendered. That engineers have failed in this regard is evidenced by the fact that almost without exception our best engineers *never* acquire a competence by the legitimate practice of their profession. Like other men, they are sometimes fortunate in an outside speculation, and many abandon the profession and seek for larger returns as contractors; but this does not invalidate the fact that the professional practice of the engineer in this country is *not* remunerative. That this is not a necessity is shown by the many engineers in foreign lands who become men of wealth and influence. *There*, when a man builds a large and important work, he is knighted and made much of (the latest instance being the knighting of Sir James Brunlees on the recent completion of the tunnel under the Mersey, at Liverpool); here he is discharged at perhaps a month's notice, and often before he has had an opportunity of putting on those last finishing touches of which the necessity is not known by his successor, or which are utterly neglected by him. Salaries of $250 per day, and even more, for a month continuously, are not uncommon among English engineers, but such fees are unheard of here American *architects* have gradually come to the agreement to charge five per cent. upon the total cost of a work for plans, specifications, estimates, detailed drawings, and such superintendence as is needed to insure a proper rendering of the specifications; but this does not include the payment of a clerk of works, or for extra

services in the matter of securing site or anything outside of the work itself, and the charge is greater on small buildings. In the matter of the Tower Bridge, in London, now under construction, the general design was made by the City Architect, but the engineering features were worked up by an engineer. The total estimated cost, as presented to Parliament, was over $3,000,000, and, after considerable controversy, the sum of $150,000, or five per cent. on the estimate, was voted by the Court of Common Council as the rightful payment for the service, to be divided between the architect and engineer as they might agree. This was spoken of as being the "standard commission." Now, while it may not be practicable for us to make this a standard at the present, there is no reason why it may not be a guide where there is no other. Those who have not considered the matter will be startled at the difference between this and the amounts our engineers ordinarily receive. Of course, such a standard cannot be reached in a moment; but it will never be reached if no effort is made. It is not the part of prudence to attempt reforms by violent changes, and I would be far from recommending anything like the unwise methods too often pursued, but we should all set our faces in the right direction. Let the community learn that the engineer must be an educated man; that to meet the ever-widening calls upon his skill made necessary by the great works of recent times, and the greater ones following on every advance accomplished, he must call to his aid all science, both ancient and modern; that he must know of the labors of others and use them to the best interests of his fellow men, and that the widest scholarship is now a necessity, and, when this lesson is learned, men will begin to understand that engineering is *indeed* a profession, and worthy of all the emoluments so freely accorded to the other learned professions in the land. It is but just that since from his position as judge and arbiter on the enterprises he helps to develop, he is precluded from investing in them, he should be fully paid for professional services.

In connection with the question of a high standard of professional honor arises a practice (to be deprecated) which is sometimes indulged in, of an engineer acting as adviser and recommending in that capacity an article of which he is the patentee, or in which he is personally interested. An engineer has no right to have any other interest than that of his employer; he degrades the profession and brings discredit upon it whenever he allows himself to be placed in a position where he is actuated by divided motives. He may come forward *avowedly* as the advocate of a special contrivance or method, and be entirely blameless, but he may *not* accept service as an engineer, and while acting as such, so shape reports or designs as to favor his own interests. An anecdote is related of Mr. Alfred W. Craven, when engineer of the Croton aqueduct, that at one time he had a water meter brought to his notice very favorably, and with the request that he take $1,000 of the stock. He said he had no money, but the promoter said that need make no difference, *he* would see to that. As the man left the room, Mr. Craven said: "There is one thing I want to say before you leave, that so long as I am in the department no meter that I am interested in can ever be introduced on the work." And it never was.

There is another indirect injury done to the profession, which is caused by the rivalry between the large firms connected with the building of bridges and other engineering operations. These furnish information and designs presumably without pay, but really the cost enters into expenses, and has to be charged on the cost of the product. There is much to be said on both sides of this question. Uniformity of design certainly tends to cheapen production, but there will also be a tendency to a sameness of thought and to quenching the spirit of investigation and progress. Centralization is the inevitable sequence of the effort to furnish such work at the lowest cost, and the engineers, who are the brains of such establishments, lose their individuality and become but parts of a great machine. It is quite certain that the fairest way of treating the matter would be for a reasonable charge to be always made for designs so furnished.

I come next to a duty which by many seems never to have been even thought of. I refer to the obligation resting upon every man to make known the results of

all professional practice, which have novelty or are of value for any other reason. Here the selfish spirit is too apt to rule, with the underlying idea that if technical knowledge be made public others will seize upon it, and by competition interfere with the chances of employment that would otherwise ensue upon exclusive control. It may be questioned whether, even upon this low plane of self interest, one's purposes are not best served by publicity. As between a man who has made it evident both practically and by proper publication that he *knows* how to do a certain thing and a man who follows confessedly as a copyist, the first will assuredly be the most likely to be sought out when the same problem is presented a second time. Numerous instances could be pointed out of recent occurrence, but it is not desirable to go further in this direction; we are not concerned at the present with the financial but with the *ethical* question—what is our duty? A digression may here be pardoned for the purpose of pointing out the position which every professional man holds as a unit in the great mass of humanity, as a factor in our modern civilization, and as a debtor to the world of science, literature and art—to do what he can to repay in kind that which he has so bountifully received. He cannot "live to himself alone," even if he would. From the time of his birth he is under the protection of laws which are the outgrowth of centuries of thought and experience, reacted upon, ameliorated, and molded by the principles of the Christian faith. He is under "tutors and masters" who spend time and labor in correcting his mistakes, showing him the sources of knowledge and leading him by plain paths to the fountain-head. If the labor of others for all the years gone by had not supplied that fountain, in vain would he seek to drink. Generous men everywhere have recorded facts, experiments, theories, experiences, designs, statistics, in order that he "may enter into their labors," and progress from the high vantage ground thus ready to his hand. In view of all this, can any man rightly say that *he* has no duty to perform in return? or what he discovers is his own, and he will keep it to himself? I verily believe that it is lack of thought which allows the experience gained on so many important works to pass into oblivion and be lost to the world. Lack of time is the usual excuse, but lack of inclination is in many cases the real reason. Whatever it may be, let us see to it that we are not among the delinquents. I would not urge that this be done in a spirit of pride; on the contrary, when a man thinks soundly on such matters and sees how really little of his work is entirely his own, he must ever feel humbled. I would, however, that every one shall feel it to be a sacred duty to record his professional experiences in some proper way, by reports, by papers to societies, or by discussions in technical journals, for the benefit of those who shall follow him. The publishing of full reports might be made more common if we were always faithful in urging the duty upon boards of direction, and such reports are considered by engineers the most satisfactory sources for the latest professional information.

The last duty to which I propose to call your attention is a very practical one, which in several very prominent instances of late has been but imperfectly performed. I refer to the obligation always resting upon an engineer, of making all statements on which proposals are asked in lettings of work, clear and unmistakable. All specifications should be explicit, and state, as nearly as language can, just what the contractor will be called upon to do, and all information attainable as to the nature of the site, difficulties of foundation, etc., should clearly set forth. In doing this the engineer should remember that the contractor also has rights which should be fully cared for, and not try to get an undue advantage by any trick of language. One of the cases referred to in which this duty was imperfectly performed was in the specifications issued for the Hawkesbury Bridge, now under contract to be erected near Sydney, in New South Wales, and which will be the most important structure yet undertaken in the Southern Hemisphere. Here is a bridge which is to cost over one and a-half millions of dollars, and of which, in referring to the designs submitted, London *Engineering* says as follows: "A bare glance at the designs shows either the piers are unnecessarily massive in some cases, or undoubtedly too slender in others. This

great want of uniformity is due, no doubt, to a limiting pressure on the foundations not being specified in the conditions, though minute instructions were given for the superstructure. It seems probable that this lack of information or of conditions regarding the doubtful and most costly portion of the work, may be a reason why so few firms known as bridge builders appear to have availed themselves of the opportunity of tendering, so reducing the competition, to the *disadvantage* of the colony." In a large work nearer home, a somewhat similar experience has been had, if reports in the papers are to be credited. It seems almost a truism to say an engineer is unfaithful to duty, whenever he allows vagueness to enter in any form into his work, especially in so important a matter as a specification. I know that an engineer is often hurried to bring forth results, and to try sometimes to accomplish impossibilities in the matter of speed; but an energetic protest would in most cases secure the time required; and when it is made perfectly clear that uncertain borings and insufficient examination as to site, indistinctness in requirements or immature plans, will be invariably followed by an increase in amount of bids to cover the factor of ignorance, there are few boards which cannot be influenced to a right decision. An engineer is not responsible for additional cost, when too short a time is allowed for proper development of a scheme, or when plans are substantially changed after estimates are made; but he is justly held accountable for wide departures from estimates when time is given for full preparation.

I have thus brought before you some of the ways in which the best of us are at times found wanting. In the rush and turmoil of active practice, and the rapid advances the profession is making in all directions, it behooves us at times to pause and see whither we are drifting, and to adjust our lives anew to the increased responsibilities thrown upon us. We are not alone in this regard. Men of all other professions may take some portion of these lessons to heart. As men and citizens, unless we enter fully into the idea and the desire that the world may be in some measure made better and happier from our having lived in it, we have not only much to learn, but we are missing the chiefest end of our existence. We shall reach our most perfect manhood only as we do *all* our work under the fullest appreciation of the meaning contained in that one word—*duty*.

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# REFRIGERATING AND ICE-MAKING MACHINERY AND APPLIANCES.

By T. LIGHTFOOT.

Read before the Institution of Mechanical Engineers.

## I.

The subject of refrigerating and ice-making machinery has not hitherto, so far as the author is aware, been dealt with in a comprehensive manner by any engineering society. The purpose, therefore, of the present paper is to describe the various systems at present in use, giving also short sketches of their development, together with some considerations respecting their practical application and working, in the hope that this may prove an acceptable contribution to the *Proceedings* of the institution, and lead to a profitable discussion upon a subject, the importance of which is daily becoming more manifest.

The primary function of all refrigerating and ice-making apparatus is to abstract heat, the temperature of the refrigerating agent being of necessity below that of the substance to be cooled. It is obvious, however, that, without provision either for rejection of the heat thus abstracted, or for renewal of the refrigerating agent, equalization of temperature would ultimately ensue, and the cooling

action would cease. In practice, if the machine is to work continuously, one or other of these means must be adopted; and a complete refrigerating machine therefore consists of an apparatus by which heat is abstracted, in combination either with some system for renewing the heat-absorbing agent, or, as is more usually the case, with a contrivance whereby the abstracted heat is rejected, and the agent is restored to a condition in which it can again be employed for cooling purposes. The subject can be conveniently dealt with under the four following heads:

1. Apparatus for abstracting heat by the melting of a solid.
2. Machinery and apparatus for abstracting heat by the evaporation of a more or less volatile liquid.
3. Machinery by which a gas is compressed partially cooled while under compression, and further cooled by subsequent expansion in the performance of work, the cooled gas being afterwards used for abstracting heat.
4. Considerations as to the applications of the various systems.

### I.—*Apparatus for Abstracting Heat by the Rapid of a Solid.*

This is probably the oldest method of artificial cooling. When a substance changes its physical state, and passes from the solid to the liquid form, the force of cohesion is overcome by the addition of energy in the form of heat. The effect may be produced without change in sensible temperature, if the heat be absorbed at the same rate as it is supplied from without, Thus, as is well known, the temperature of melting ice remains constant at 32° Fahr.; and any increase or decrease in the heat supplied merely hastens or retards the rate of melting, without affecting the temperature. Mixtures of certain salts with water or acids, and of some salts with ice, which form liquids whose freezing points are below the original temperatures of the mixtures, do not, however, behave in this way; for under ordinary circumstances the tendency to pass into the liquid form is so strong, that heat is absorbed at a greater rate than it can be supplied from without. The store of heat of the melting substances themselves is therefore drawn upon, and the temperature consequently falls until a balance is set up between the rate of melting and the rate at which heat is supplied from outside. This is what takes place with ordinary freezing mixtures. The amount of the depression in temperature appears to depend to some extent on the state of hydration of the salt, and the percentage of it in the mixture. Almost the only salts used are those of certain alkalies, few others possessing the requisite solubility at low temperatures. A list of the freezing mixtures usually employed is given in the appended table I.

Such a method of abstracting heat is extremely convenient for the laboratory, and for some other special purposes. Attempts have also been made to apply it commercially on a large scale for the manufacture of ice and for cooling. The late Sir William Siemens constructed an ice-making apparatus in which calcium chloride was employed. The reduction in temperature produced by this salt in water is about 30° Fahr.; but as this was not sufficient for freezing when the initial temperature of the water was about 60° or 65° Fahr., a heat interchanger was introduced, by means of which the spent liquor at about 30° was utilized for cooling the water before it was mixed with the salt; and to the extent of this cooling the degree of cold produced was intensified. The salt was recovered by evaporation, and used over again. Although this apparatus worked well and produced ice, the inventor himself considered the process inferior to mechanical methods, and abandoned it. In the Toselli machine a mixture of ammonia nitrate and water is used, by means of which a reduction in temperature of about 40° Fahr. is obtained. The apparatus consists of a vessel in which the solution of the salt is effected, and an ice can containing several slightly tapering molds of circular cross section and of varying sizes. The molds being filled with water are introduced into the freezing mixture; and in a few minutes ice is formed round the edges to the thickness of nearly an eighth of an inch. The rings or tubes of ice are then removed and placed one within the other, so forming a small stick of ice.

Ammonium nitrate is also employed in a machine recently brought out in the United States for the production of ice

on a large scale. In one form of this apparatus, intended chiefly for domestic purposes, a series of annular vessels, one within the other, is used; the molds in which the ice is to be formed being placed in the center. The reduction of temperature produced by the freezing mixture in in the outermost vessel cools the water in the second; and this, on salt being added, cools the third; and so on. In this way the cold is very much intensified at the center, and a low temperature can be produced independent of the initial temperature of the water. The number of rings employed varies according to the effect to be produced and the conditions under which the apparatus is applied. The annular vessels, together with the ice molds, are carried in a wood casing supported on bearings, the only motive power required being that necessary to rotate the vessels slowly, so as to promote the solution of the salt. Another form of apparatus, designed for continuous use on a large scale, consists of a vessel into which ammonium nitrate is automatically fed, and in which it enters into solution with water previously cooled in an interchanger by the spent liquor, after the latter has left the ice-making tanks or cooling-rooms. The cold brine thus produced is circulated by a pump through the ice-tanks, or through pipes placed in the rooms it is desired to cool; and is returned through the interchanger to an evaporating tank, where by means of heat the water is driven off and the salt recovered. This is practically Sir William Siemens' apparatus in a somewhat extended form. The cost of producing 15 tons of ice per twenty-four hours with such an apparatus of suitable capacity is stated at 7s. per ton, with good coals at 15s. a ton, and exclusive of depreciation and repairs. This, however, is probably much too low an estimate, being based on the erroneous assumption that 1 lb. of coal is capable of evaporating 20 lbs. of water. Nearly the whole of the coal is used for evaporating the water in recovering the salt, the quantity being given at $2\frac{1}{2}$ tons of coal for every 15 tons of ice. If however, this has been calculated on an evaporative duty of 20 lbs. of water per lb. of coal, the amount actually used will probably be about 5 tons of coal, which would make the cost per ton of ice 9s. 3d. instead of 7s. On the other hand, it must be remembered that under certain climatic conditions much of the water could be evaporated in the open air, without the use of fuel; in which case the coal consumption, and therefore the cost of ice production, would be greatly lessened.

II.—*Machinery and Apparatus for Abstracting Heat by the Evaporation of a more or less Volatile Liquid.*

When a liquid changes its physical condition, and assumes the state of vapor, heat is absorbed in increasing the energy of the molecules. This heat is absorbed without change in sensible temperature; and the amount thus disposed of is usually called the latent heat of vaporization. For different liquids different quantities of heat are required; and for the same liquid the amount varies somewhat according to the pressure at which vaporization occurs. Other things being equal, the liquid with the highest latent heat will be the best refrigerant, because for a given abstraction of heat the least weight of liquid will be required, and therefore the power expended in working the machine will be the least. The principal systems in which the evaporation of liquids is employed may be treated under the following subdivisions:—

*A.* Apparatus in which the refrigerating agent is rejected along with the heat it has acquired.

*B.* Machines in which heat only is rejected, the refrigerating agent being restored to its original physical condition by means of mechan ical compression, and by cooling when under compression.

*C.* Apparatus in which heat only is rejected by allowing the refrigerating agent to change its physical condition by entering into solution with a liquid, from which it is afterwards separated by evaporation and recovered.

*D.* Machinery and apparatus in which heat only is rejected, by changing the physical state of the refrigerating agent by a combination of both mechanical compression and solution, with cooling.

*System A.*— This is generally known as the vacuum process, for as the refrigerating agent itself is rejected, the only

agent of a sufficiently inexpensive character to be employed is water, and this, owing to its high boiling-point, requires the maintenance of a high degree of vacuum in order to produce ebullition at the proper temperature. The vapor tensions of water at temperatures up to boiling-point at atmospheric pressure are given in the appended table II., from which it will be seen that at 32° Fahr. the tension is only 0.089 lb. per square inch. In ice-making, therefore, a degree of vacuum must be maintained at least as high as this. The earliest machine of this kind appears to have been made in 1755, by Dr. Cullen, who produced the vacuum by means of an air-pump. In 1810 Leslie, combining with the air-pump a vessel containing strong sulphuric acid, for absorbing the vapor from the air drawn over and so assisting the pump, succeeded in producing an apparatus by means of which 1 to 1½ lbs. of ice could be made in a single operation. Vallance and Kingsford followed later, but without practical results; and Carré, many years afterwards, embodied the same principle in a machine for cooling and for making small quantities of ice, chiefly for domestic purposes. His machine, which is still sometimes used, consists of a small vertical vacuum pump, worked by hand, either by a lever or by a crank, which exhausts the air from the carafe or decanter containing the water or liquid to be frozen or cooled. Between the pump and the water vessel is a lead cylinder, three-quarters full of sulphuric acid, over which the air, and with it the vapor given off from the liquid, is caused to pass on its way to the pump. The vacuum thus produced causes a rapid evaporation, which quickly lowers the temperature of the water; and if the action is prolonged for about four or five minutes, the water becomes frozen into a block of porous opaque ice. The charge of acid is about 4½ pints, and it is said that from 50 to 60 carafes of about a pint each can be frozen with one charge. So long as the joints are all tight and the pump is in good order this apparatus works well; but in practice it has been found troublesome and unreliable, and consequently has never come into anything like general use.

In 1878 Franz Windhausen, of Berlin, brought out a compound vacuum-pump for producing ice direct from water on a large scale, without the employment of sulphuric acid; and also an arrangement in which sulphuric acid could be used, the acid being cooled by water during its absorption of the vapor, and afterwards concentrated, so that a fresh supply was rendered unnecessary. This apparatus was improved on in 1880; and in 1881 a machine nominally capable of producing 15 tons of ice per twenty-four hours was put to work experimentally at the Aylesbury Dairy, at Bayswater, being afterwards removed to Lillie Bridge, where the author believes it now is. The installation was fully described and illustrated by Carl Pieper in a paper read before the Society of Engineers, in November, 1882, and by Dr. John Hopkinson, at the Society of Arts, about the same time.* It consists of six slightly tapered ice forming vessels of cast iron, of circular cross section, closed at their bottom ends by hinged doors with air-tight joints, into which water is allowed to flow at a regular speed through suitable nozzles, the cylinders being steamjacketed in order to allow the ice to be readily discharged. The upper parts of these vessels communicate with the pump through a long, horizontal iron vessel of circular section containing sulphuric acid which, when the machine is in operation, is kept in continual agitation by means of revolving arms. The acid vessel is surrounded with cold water which carries off most of the heat liberated during the absorption of the vapor. The pump has two cylinders, one double-acting of large size, and a smaller single-acting one. The capacities of these cylinders per revolution are as 62 to 1. The air and whatever vapor has passed the acid are drawn into the large pump, which partially compresses and delivers them into a condenser. Here part of the vapor is condensed by the action of cold water, the remainder passing along with the air to the second pump, where they are compressed up to atmospheric tension, and discharged. The advantage gained by the use of a compound pump is due to the action of the intermediate condenser, and to the compression being performed in two stages, by which the losses from

* *Transactions of the Society of Engineers*, 1882, page 145; *Journal of the Society of Arts*, 1882, vol. xxxi., page 20.

the clearance spaces in the large pump are rendered much less than they would be if compression to atmospheric pressure were accomplished in a single operation. The effect of the pump is said to be such that a vacuum of half a millimeter of mercury, or about 0.0097 lb. per square inch, can be continuously maintained; though, in actual work about $2\frac{1}{2}$ millimeters, or 0.0484 lb. per square inch is as low as is necessary. The concentration of the acid is effected in a lead-lined vessel, in which is a coil of lead piping heated by steam, the pressure in the vessel being kept down by means of an ordinary air pump. No acid pump is needed, as the transfer from one vessel to another is effected by the pressure of the atmosphere. The comparatively cool weak acid on its way to the concentrator is heated in an interchanger by the strong acid returning from the concentrator. Six blocks of ice, each weighing about 560 lbs., are formed in about twenty minutes after starting. The charge of acid is said to serve for three makings of ice, after which it becomes too weak, and requires to be concentrated.

The water being admitted into the ice-forming vessels in fine streams offers a large surface for evaporation, and is almost immediately converted into small globules of ice, which fall to the bottom and become cemented together by the freezing of a certain quantity of water that collects there. This water being in a violent state of ebullition, the ice so formed is not solid, but contains spaces or blowholes, which, as soon as the block is discharged from the vessel, become filled with air and cause opacity. Several attempts have been made to produce transparent ice by the direct vacuum process, but so far without success. Distilled water, or water deprived of air has been tried, and hydraulic pressure has been used for compressing the porous opaque blocks, but neither plan has been found practicable commercially. It would appear, indeed, that the only way to make clear ice by the vacuum process is by forming it in molds, subjected externally to the action of brine previously cooled by the evaporation of a portion of its water. The cost in this case would necessarily be greater; but the ice would be solid and transparent and would consequently have a higher commercial value. The latent heat of liquefaction of water being 142.6° Fahr., the total heat to be extracted in order to produce 1 ton of ice from 1 ton of water at 60° Fahr., is 382,144 Fahr. lbs. units. Taking the latent heat of evaporization of water at 32° Fahr. to be 1091.7, it is obvious that 350 lbs. must be evaporated to make the ton of ice. But, in addition, the sensible heat of evaporated water, which entering at 60° would leave at about 32°, would have to be taken off, and this would require the evaporation of about $9\frac{1}{4}$ lbs. more, making a total of about 360 lbs , without allowance for loss by heat entering from without, which would be considerable. The total water actually used is given by Mr. Pieper at 12 tons per ton of ice, including the quantity required for cooling purposes. The fuel consumption is stated to be 180 lbs. of coal per ton of ice, but the author understands a much larger quantity is actually required. It is consumed for generating steam for driving the vacuum pump and the concentrator air pump, and for evaporating the water absorbed by the acid. According to Dr. Hopkinson, the cost of making 1 ton of opaque ice is 4s.; but the author believes experience has shown that a much higher figure is required to cover the necessary expenses for repairs and maintenance, which in some parts of the apparatus are very heavy. Windhausen's machine has not met with any extended application in this country, owing, no doubt, to the opaque and porous condition of the ice produced by it, and to the large and cumbrous nature of the plant, which must doubtless require great care and supervision in working.

A vacuum apparatus for refrigerating liquids by their own partial evaporation, and for making ice, was brought out in 1878 by James Harrison. Its chief feature is the revolving cylinder or pump, which affords a simple and efficient means of exhausting large volumes of vapor of low tension, without incurring the loss from friction of ordinary piston packings, and the trouble of keeping them tight and in good working order, while at the same time the first cost is much reduced. The pump consists of a hollow iron cylinder, revolving on a horizonal axis, and divided into compartments by longitudi-

nal compartments of L section. It is partially filled with a non-evaporable or one which evaporates only at a temperature considerably in excess of that at which the refrigerating liquid is evaporated, and which is also chemically neutral to the vapor that is brought in contact with it. In practice, oil is the liquid used. The refrigerating or ice-making vessels, of any convenient form, are connected by a pipe with one end of a fixed hollow axle on which the cylinder revolves; and inside the cylinder another pipe rises up above the level of the liquid the longitudinal partitions being stopped short at one end to enable this to be done. The compartments move around mouth downwards, carrying with them the vapor with which they are charged, and compressing it to an extent measured by the distance they dip below the surface of the liquid, until, when the lowest position is approached, the compressed vapor is liberated, and rises into a fixed hood near the center, in communication with a second hollow axle at the opposite end of the cylinder to that at which the vapor enters. Through this second axle the compressed vapor passes to a surface evaporative condenser, in which it is partly condensed by the combined action of direct cooling and the partial evaporation of water trickling over the surface; the water of condensation, together with any air, is then compressed to the tension of the atmosphere by a small pump, and discharged. By this process, the author is informed, it is expected to produce opaque ice on a large scale at a cost of about 1s. per ton. The fuel consumption will certainly be very small, because friction, which is a large item in the Windhausen apparatus, is here to a large extent eliminated. There would also be a saving of all the fuel used in concentrating the acid, and of much of the water required for cooling purposes, besides a reduction in the first cost of the plant, and in the expense of maintenance.

*System B.*—This is known as the compression process, and is used with liquids whose vapors condense under pressure at ordinary temperatures. Although, prior to 1834, several suggestions had been made with regard to the production of ice and the cooling of liquids by the evaporation of a more volatile liquid than water, the author believes that the first machine really constructed and put to work was made by John Hague in that year, from the designs of Jacob Perkins. According to Sir Frederick Bramwell,* the liquid used was one arising from the destructive distillation of caoutchouc. The machine, so far as the author is aware, was never put to work outside of the factory where it was constructed. The water to be frozen was placed in a jacketed copper pan, the jacket being partially filled with the volatile liquid, and carefully protected on the outside with a covering of non-conducting material. A pump drew off the vapor from the jacket, and delivered it compressed into a worm, around which cooling water was circulated, the pressure being such as to cause liquefaction. The liquid collected at the bottom of the worm, and returned to the jacket through a pipe, to be again evaporated. This apparatus, though in some respects crude, is yet the parent of all compression machines used at the present time, the only improvements made since the year 1854 having been in matters of constructive detail. The next advance was made in 1856 and 1857, by James Harrison, who brought out a machine embodying the same principles as that of Perkins, but worked out on a larger and more practical scale. It was taken up by the late Mr. Siebe, and was the first ice-making machine that really came into practical use in this country, and was employed on a commercial scale. An improved apparatus of this kind, in which ether is used as the refrigerating agent, is still manufactured by Messrs. Siebe, Gorman & Co. The vapor tensions of ether are given in the appended Table II. It is not a very volatile liquid, of specific gravity 0.720, having a latent heat of evaporization of 165°, and a specific gravity of vapor of 2.24 compared with air. Its boiling-point at atmospheric pressure is 96° Fahr. Messrs. Siebe, Gorman & Co.'s machine, applied to the manufacture of clear ice, consists of a refrigerator, a water-jacketed pump, driven by a surface-condensing steam-engine, an ether-condenser, and ice-making tanks containing copper molds, around which brine, cooled to a

* *Journal of the Society of Arts*, 1882, vol. xxxi., p. 77.

low temperature in the refrigerator, is circulated by a pump. The refrigerator is a cylindrical vessel of sheet copper, containing clusters of horizontal, solid-drawn, copper tubes, through which the brine successively circulates. The shell is connected with the pump by a pipe, the liquid ether from the condenser being admitted through a small pipe having a cock, which is so adjusted as to pass the precise weight of ether that the pump will draw off. What this weight is de pends entirely on the pressure at which evaporation occurs; the greater the density of the vapor, the greater is the weight drawn off at each revolution of the pump. The pressure at which evaporation occurs is defined by the temuerature to which it is de.ired to reduce the brine, the boiling-point of the ether being regulated so as to give the required reduction of temperature, and no more, otherwise the apparatus would not work up to its full capacity. The condenser consists of a cluster of solid-drawn copper tubes placed horizontally in a wood tank, through which cooling water is circulated, the amount of water required in this country being 150 gallons per hour for every ton of ice made per twenty-four hours. With the temperature of cooling water available in this country, liquefaction generally occurs at a pressure of about 3 lbs. per square inch above the atmosphere, but in a warm climate the pressure needed may reach as much as 10 or even 12 lbs.

In another apparatus the ice is made in cans or molds. The molds, of sheet copper or steel, are filled with the water to be frozen, and are suspended in a tank, through which is kept up a circulation of cold brine from the refrigerator. As soon as the ice is formed the molds are removed and dipped for a few minutes in warm water to loosen the ice, which is then turned out. The sizes of the molds vary a good deal, according to the capacity of the machine and the purpose for which the ice is to be used. A common plan is commence with a thickness of three inches for a production of 1 ton per twenty-four hours, and to go up to 9 inches for 10 tons and upwards. The thickness exercises an important bearing upon the number of molds to be employed for any given output; for while a 3-inch block can be frozen in eight hours, one 9 inches thick will take about thirty-six hours. The time, however, varies also according to the temperature at which the brine is worked. For an ether machine, such as that just described, the brine temperature may be taken at from 10° to 15° Fahr. Another method is that known as the cell system. This consists of a series of cellular walls of wrought or cast iron, placed from 12 to 16 inches apart, the space between each pair of walls being filled with the water to be frozen. The cool brine circulates through the cells, the ice gradually forming outside, and increasing in thickness until the two opposite layers met and join together. If thinner blocks are required freezing may be stopped at any time, and the ice removed. In order to detach the ice from the walls, it may either be left for a time after the circulation of the brine has been stopped, or a better and quicker plan is to pass some warmer brine through the cells. In order to produce transparent ice it is necessary that the water should be agitated during freezing, so as to allow the escape of the air set free. When molds are used, this is generally done by means of arms having a vertical or horizontal movement, which are either pushed up by the ice as it forms, leaving the block solid, or work backwards in the center of the mold, dividing the plock vertically into two equal pieces. With cells, agitation is generally effected from the bottom by means of paddles. The ice which forms first on the sides of the molds or cells is generally transparent enough, even without agitation. The opacity gradually increases towards the center, where the two layers meet and join together; agitation is therefore more necessary towards the end of the freezing process than at the beginning. As the quantity of air held in solution by water decreases as its temperature is raised, it is obvious that less agitation will be required in hot than in temperate climates; for this reason, in India and elsewhere, agitation is frequently dispensed with altogether.

Machines using ether as the refrigerating medium are also largely made by Messrs. Sidely & Co., of Liverpool, and Messrs. West & Co., of Southwark; but they present no special features which are not embodied in the apparatus already

described, the points of difference being in details to which it is not necessary to refer. As already stated, the working pressure in the refrigerator must depend upon the extent of the reduction in temperature desired, bearing in mind that the higher the pressure the greater will be the work that can be got out of any given capacity of pump. The liquefying pressure in the condenser depends on the temperature of the cooling water and on the quantity that is passed through in relation to the quantity of heat carried away; and this pressure determines the mechanical work to be expended. In any given machine the work may be accounted for as follows:

Friction.
Heat rejected during compression.
Heat acquired by the refrigerating agent in passing through the pump.
Work expended in discharging the compressed vapor from the pump.
Against which must be set—
Work done by the vapor entering the pump.

Assuming that vapor alone enters the pump, the heat rejected in the condenser is—

Heat of vaporization acquired in the refrigerator, with the correction necessary for difference in pressure.

Heat acquired in the pump, less the amount due to the difference between the temperature at which liquefaction occurs and that at which the vapor entered the pump.

Though circumstances vary so much that no absolutely definite statement can be made as to the working of ether machines in general, the following particulars, taken from actual experiment in this country, will serve to show what may be expected under ordinary conditions:

| | |
|---|---|
| Production of ice, tons per 24 hours | 15 tons. |
| Production of ice, lb. per hour. | 1,400 lbs. |
| Heat-units per hour abstracted in ice-making | 245,000 units |
| Indicated horse-power in steam cylinder, excluding that required for circulating the cooling water, and for working crane, &c. | 83 I. H. P. |
| Indicated horse-power in ether pump | 46½ I. H. P. |
| Thermal equivalent of work in ether pump, units per hour | 119,261 units |
| Ratio of work in pump to work in ice-making | 1 to 2.05 |
| Temperature of water entering condenser | 52° Fahr. |

Assuming the coal consumption per indicated horse-power to be 2 lbs. per hour, and the price of coal 15s. a ton, the total cost of producing transparent block ice in this country on the ether system, with such a machine as that just referred to, may be taken at about 5s. per ton, excluding allowance for repairs and depreciation. The production of ice would be about 8.3 tons per ton of coal. For cooling water and other liquids another machine is used; but in this case the ice-boxes are dispensed with, the liquid being passed direct through the refrigerator without the employment of brine. Methylic ether, a liquid with a latent heat of vaporization of—, and which boils under atmospheric pressure at 10 5° below zero Fahr., has been employed by Tellier in machinery of practically similar design to that used with ordinary ether. Tellier's apparatus has never come into use in this country, and need not be further dwelt on, for beyond the difference in size of pump, and the obvious alterations due to the higher working pressures, it presents no features of importance. Some years ago Raoul Pictet, of Geneva, successfully introduced sulphur dioxide as a refrigerating agent, and in France a large number of his machines have been made and put to work. In this country, also, they have been used, but to a much smaller extent. It is a liquid with a latent heat of vaporization of 182°, and under atmospheric pressure boils at 14° Fahr. This machine is also of similar design to those in which ether is employed; but Pictet combined the refrigerator with the ice-making tanks, the brine being circulated by means of a fan. In this way the space occupied was reduced, and the efficiency somewhat increased. The cost of producing ice by the Tellier and Pictet machines may be taken at practically the same as that by the other process. Some of the more volatile derivatives of coal tar have been used in compression machines, especially in the United States; but it will be unnecessary to refer to them in detail, as their application has been exceedingly limited.

Anhydrous ammonia, which may now

be obtained as an article of commerce, has of late years been very largely introduced as a refrigerating agent, more especially in Germany and in the United States. Under atmospheric pressure, anhydrous liquid ammonia boils at 37.30° below zero Fahr., and under this condition its latent heat of vaporization is 900°. So far as the cycle of operation is concerned, it is precisely the same as for either; the liquid is vaporised in the refrigerator by the action of the pump, which then compresses the vapor, and delivers it into the condenser at such pressure as to cause it to liquefy. In the construction of ammonia machines, however, there are two essential points of difference. For, in the first place, the pressure of the ammonia vapor is much higher than that of ether at the same temperatures, its tension at 60° Fahr. being 108 lbs. per square inch; and, secondly, owing to the action of ammonia on copper, no brass or gun metal can be used in any part with which the gas or liquid comes into contact. One of the chief difficulties encountered in the compression of ammonia is leakage at the pump gland. The gas is extremely searching, and even at the comparatively low pressure of 30 lbs. per square inch above the atmosphere it will readily find its way through an ordinary gland; while at the pressure existing in the condenser, which may be taken at from 150 to 180 lbs. per square inch, this tendency is of course much aggravated. In order to minimise the leakage and to simplify the construction of the gland, the pumps are frequently made single-acting, as in this way the gland is exposed only to the refrigerator pressure, which is seldom above 30 lbs. It is also usual for glycerine, or some lubricant that does not saponify with ammonia, to be injected into the pump, so as to form a liquid seal for the gland, and in some cases for the piston as well; this is the general practice in the United States. In Germany, on the other hand, where the compression machine has been very largely applied, the double-acting pump is more usual. To lessen leakage, Linde provides a chamber in the gland box, into which glycerine or some suitable lubricant is constantly forced at a slightly greater pressure than that prevailing in the condenser, so that the tendency is for the lubricant to leak inwards, instead of ammonia outwards. Any lubricant that does get into the pump passes out with the ammonia, and is separated from it in a suitable vessel. Up to the present time, so few ammonia compression machines have been constructed in England, that as yet no general practice has been established; but, on the whole, the feeling seems to be in favor of the single-acting pump.

With regard to the other parts of the apparatus, but little need be said. Wrought-iron coils or zig-zags are used for both the condenser and the refrigerator, their precise form depending on the fancy of the designer, The refrigerator is generally combined with the ice-tanks, the cooling pipes being placed either below or at the side of the molds, sometimes in a separate compartment and sometimes in the same tank. With the cell system an independent refrigerator is used, the cooled brine being circulated by a pump in a similar manner to that described for the ether system. Owing to the low temperature which may be attained by the use of ammonia, care has been taken in the selection of a brine that will not congeal with the degree of cold to which it will be subjected. A solution of calcium or magnesium chloride in water is generally used. The mechanical work expended in compressing ammonia may be accounted for in a precisely similar manner to that expended in the compression of ether. Notwithstanding that the degree of compression is so much greater with ammonia than with ether, the energy expended in compressing, heating, and delivering the gas is less, owing to the much smaller weight of ammonia required to produce a given refrigerating effect, the weights being in the inverse ratio of the heats of vaporization, or as one to 5.45. For this reason the cost of making ice is much less with ammonia than with ether, one ton of coal being capable of producing as much as 12 tons of ice in well-constructed ammonia apparatus having a capacity of 15 tons per 24 hours. With coal at 15s. a ton, the cost of making ice by the ammonia compression system may be taken at about 3s. 9d. per ton for a production of 15 tons per 24 hours, exclusive of allowances for repairs and depreciation. Through the

courtesy of the manager of the Linde British Ice Company, the author is enabled to give the following results of a test made by a committee of Bavarian engineers, with a machine erected in a brewery in Germany. The test, he believes was carried out in an impartial manner; and though it is not put forward by the Linde Company as showing the results attained in the ordinary working of their machines, it will nevertheless be of interest as indicating what may be expected under the most favorable conditions:

| | |
|---|---|
| Nominal capacity of machine, tons of ice per 24 hours | 24 tons. |
| Actual production of ice, tons per 24 hours | 39.2 tons. |
| Actual production of ice, lbs. per hour | 3,659 lbs. |
| Heat-units abstracted per hour in ice making | 731,800 units |
| Indicated horse-power in steam cylinder, excluding that required for circulating the cooling water and for working cranes | 53 I. H. P. |
| Indicated horse-power in ammonia pump | 38 I. H. P. |
| Thermal equivalent of work in ammonia pump, units per hour | 97,460 units. |
| Ratio of work in pump to work in ice-making | 1 to 7.5 |
| Total feed-water used in boiler, lbs. per 24 hours | 26,754 lbs. |
| Ratio of coal consumed to ice made, taking an evaporation of 8 lbs. of water per lb. of coal | 1 to 26.3 |

In this case the pumps were driven by a Sulzer engine, which developed one indicated horse-power with 21.8 lbs. of steam per hour, including the amount condensed in steam pipes. Ammonia compression machines are manufactured in this country by Messrs. Siebe, Gorman & Co., the Birmingham Refrigeration Company, and Linde British Ice Company.

*System C.*—This is known as the absorption process, and was first applied by Carré about 1850. The principle employed is chemical or physical, rather than mechanical, and depends on the fact that many vapors of low boiling-point are readily absorbed by water, but can be separated again by the application of heat to the mixed liquid. A considerable number of machines in which ammonia was used in combination with water as an absorbent were made by Carré in France; but no very high degree of perfection was arrived at, owing to the impossibility of getting an anhydrous product of distillation; the ammonia distilled over contained about 25 per cent. of water, which caused a useless expenditure of heat during evaporation and rendered the working of the apparatus intermittent. Taking advantage of the fact that two vapors of different boiling points, when mixed, can be separated by means of fractional condensation, Rees Reece brought out, in 1867, an absorption machine, in which the distillate was very nearly anhydrous. The action of the machine was briefly as follows: Ordinary liquid ammonia of commerce, of 0.880 specific gravity, was heated, and a mixed vapor of ammonia and water was driven off. By means of vessels termed the analyzer and the rectifyer, the bulk of the water was condensed at a comparatively high temperature, and run back to the generator; while the ammonia passed into a condenser, and there assumed the liquid form under the pressure produced by the heat,and the cooling action of water circulating outside. The nearly anhydrous liquid was then utilized in a refrigerator in the ordinary way, but instead of the vapor being drawn off by a pump, it was absorbed by cold water or weak liquor in a vessel called an absorber, which was in communication with the refrigerator; and the strong liquor thus formed was pumped back to the generator, and used over again. This apparatus was afterwards improved by Stanley, who introduced steam coils for causing the evaporation in the generator; and then by Pontifex & Wood, who have succeed in bringing the absorption machine to a considerable state of efficiency. Their apparatus, as applied to the cooling of liquids, consists of a generator, containing the coils, to which steam is supplied from an ordinary boiler; an analyzer, a rectifyer, and condenser; a refrigerator or cooler, in which the nearly anhydrous ammonia obtained in the condenser is allowed to evaporate; an absorber, through which weak liquor from the generator continually flows and absorbs the anhydrous vapor produced in the refrigerator; an economizer or interchanger, by means of which the cold, strong liquor from the absorber is heated by the hot, weak liquor passing from the

generator to the absorber; and pumps for forcing the strong liquor produced in the absorber back into the analyzer, where, meeting with steam from the generator, the ammonia is again driven off, the process being thus carried on continuously.

Assuming the action of the economizer to be perfect—which, of course, is a condition never met with in practice—all the heat given out by the steam in the generator coils would be found in the water issuing from the condenser, less that portion directly lost by radiation and conduction. In this case the total heat expended would be that required to vaporize the ammonia, and the water, which in the form of steam unavoidably passes off with the ammonia to the rectifyer and condenser, plus the heat lost by radiation and conduction. In the refrigerator, the liquid ammonia in becoming vaporized will take up the precise quantity of heat that was given off during its cooling and liquefaction in the condenser less the amount due to difference in pressure, and less, also, the small amount due to the difference in temperature between the vapor entering the condenser and that leaving the refrigerator. Again, when the vapor enters into solution with the weak liquor in the absorber, the heat taken up in the refrigerator is given to the cooling water, subject to slight corrections for differences of pressure and temperature. Supposing there were no losses, therefore, the heat given up by the steam in the generator, plus that taken up by the ammonia in the refrigerator, would be precisely equal to the amount taken off by the cooling water from the condenser, plus that taken off from the absorber. The sources of loss are:

Inefficiency of the economizer.

Radiation and conduction from all vessels and pipes that are above normal temperature.

Useless evaporation of water which passes into the rectifier and condenser.

Conduction of heat into all vessels and pipes that are below normal temperature.

Water passing into the refrigerator along with the liquid ammonia.

It will have been seen that the heat demanded from the steam is very much greater in the absorption system than in the compression. This is chiefly due to the fact that in the absorption system the heat of vaporization acquired in the refrigerator is rejected in the absorber, so that the whole heat of vaporization required to produce the ammonia vapor prior to condensation, has to be supplied by the steam. In the compression system the vapor passes direct from the refrigerator to the pump, and power has to be expended merely in raising the pressure and temperature to a sufficient degree for enabling liquefaction to occur at ordinary temperatures. On the other hand, a great advantage is gained in the absorption machine by using the direct heat of the steam, without first converting it into mechanical work; for in this way its latent heat of vaporization can be utilized by condensing the steam in the coils and letting it escape in the form of water. Each pound of steam passed through can thus be made to give up some 950 units of heat; while in a steam-engine using 2 lbs. of coal per indicated horse-power per hour, only about 160 units are utilized per lb. of steam without allowance for mechanical inefficiency. In the absorption machine, also, the cooling water has to take up about twice as much heat as in the compression system, owing to the ammonia being twice liquified, namely, once in the condenser and once in the absorber. It is usual to pass the cooling water first through the condenser and then through the absorber. The cost of producing clear block ice in this country, with an absorption machine of 15 tons capacity per twenty-four hours, may be taken at about 4s. per ton, with good coals at 15s. per ton, exclusive of allowance for repairs and depreciation. About 10 tons of ice can be made per ton of coal consumed, assuming an evaporative duty of 8 lbs. of water per lb. of coal.

*System D.*—In this, which is known as the binary absorption system, liquefaction of the refrigerating agent is brought about partly by mechanical compression, and partly by absorption; or else the refrigerating agent itself is a compound of two liquids, one of which liquefies at a comparatively low pressure, and then takes the other into solution by absorption. An apparatus of the first kind was

brought out in 1869, in Sydney, by Messrs. Mort & Nicolle, who used ammonia, with water as an absorbent. The machine consisted of an evaporator or a refrigerator, a pump, and an absorber. The evaporator was supplied with strong ammonia liquor, which was vaporized by means of the reduction of pressure induced by the pump, and so abstracted heat from the liquid to be cooled. The weak liquor passing out at the bottom of the evaporator was led by pipes to the pump, where it met with the ammonia vapor, along with which it was forced through cooling vessels under sufficient pressure to cause the solution of the ammonia, and the strong liquor thus formed was again passed into the evaporator. This machine was only used by the inventors in Australia, so far as the author is aware, and he has no particulars as to fuel consumption or cost of working. It was not likely, however, to be a very economical apparatus, because the whole of the water entering the evaporator with the ammonia had to be reduced in temperature, giving up it heat to the ammonia vapor, and to that extent preventing the performance of useful cooling work. But this disadvantage was in some degree compensated for by reducing the temperature of the strong liquor before it entered the evaporator by means of an interchanger, through which the very cold, weak liquor passed on its way to the pump.

In machines of the second kind, in which both liquids are evaporated at a low temperature, the foregoing objection does not exist, and though this mode of working has not as yet been introduced into this country, it has been successfully employed in the United States for several years by Messrs. De Motay & Rossi. The liquid used is a mixture of ordinary ether and sulphur dioxide, and has been termed ethylo sulphurous dioxide: its adoption was decided on after a series of experiments with numerous other combinations of ethers and alcohols with acids. In these investigations it was found that liquid ether at ordinary temperatures possessed an absorbing power for sulphur dioxide amounting to some 300 times its own volume; while at 60° Fahr. the tension of the vapor given off from the binary liquid was below that of the atmosphere. In working, both liquids evaporate in the refrigerator, under the influence of the pump, and in the condenser the pressure never exceeds that necessary to liquefy the ether. The compressing pump has less capacity than would be required for ether alone, but more than for pure sulphur dioxide. As to the cost of making ice by this process, the author has no particulars; but he believes it to be somewhat less than with ether. An interesting application of the binary system has lately been made by Raoul Pictet, who found that by combining carbon dioxide and sulphur dioxide he could obtain a liquid whose vapor tensions vere not only very much less than those of carbon dioxide, but were actually below those of pure sulphur dioxide at temperatures above 7° Fahr. This is a most remarkable and unlooked-for result, and may open up the way for a much greater economy in ice production than has yet been obtained. As to the results that have been obtained with this process, the author has no definite particulars; but he understands it is stated to give a production of 35 tons of ice per ton of coal.

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Copper mining is largely carried on in New South Wales, the most important mines being the Great Cobar, situated 497 postal miles west of Sydney, in the center of the vast plains which lie between the Macquarie and the Bogan rivers. The ore is so rich and abundant that the industry has been a very profitable one until a very recent period, notwithstanding the great distance of the mine from the settled portion of the colony. The produce of the mine has to be hauled by wagons a distance of eighty miles to Nyngan, the nearest railway station. The industry has caused a large settlement to spring up at Cobar, and it is estimated that within a radius of three miles the population is within 3,000 and 4,000. The Great Cobar Mine gives employment to about 900 persons. The company working the mine at present experiences great difficulty in getting the copper to market. The amount of refined copper produced during the year was 4,765 tons. During the year 1884 the Great Cobar Company raised 21,561 tons of ore, and smelted 23,899 tons, yielding 2,769 tons of fine copper. At the end of the year the company had ready for smelting 1,000 tons of 10 per cent. ore, 5,000 tons 8 per cent., and 2,233 tons 5 per cent. Up to the close of 1884 the company had smelted 122,795 tons of ore, the average yield of which was 13.17 per cent. of fine copper. The greatest depth of the main shaft is 564 feet, and from that diamond drills have been sunk 60 feet further. The lode at this depth is said to show a thickness of 40 feet of fair yellow sulphide ore.

# AMOUNT OF HORSE-POWER USED IN PROPELLING STREET CARS.

By AUGUSTINE W. WRIGHT.

From Proceedings of the Association of Engineering Societies.

At the present time great interest is manifested by street railway companies regarding the question of the substitution of some motive power to propel their cars other than horse-flesh. The various systems, electrical, cable, compressed air, Honigman, steam dummies, etc., etc., are prominently before the public, and each for itself claims, if not perfection, certainly that it is better than any other system.

It appears to me that great ignorance exists upon the part of inventors and street railway companies themselves as to the amount of power required to start a street car and to maintain it in motion under average conditions. The following is an attempt toward a solution of this problem. We will begin with horse-power: Watt's experiments, made with large horses of the London brewers, gave 33,000 pounds raised one foot high in one minute as the power exerted by an average horse, and this as you all know, is the allowance in figuring engine power. This is on the assumption that a horse can exert a force of 150 pounds over 20 miles per diem at the rate of 220 feet per minute, or $2\frac{1}{2}$ miles per hour during 8 hours. But the horse's power is very variable at different speeds. Tredgold's experiments gave 125 pounds; Smeaton, 100 pounds; Hatchette, 128 pounds; all 20 miles per diem at $2\frac{1}{2}$ miles per hour. Gayffier fixed the power of a strong draught horse at 143 pounds, 22 miles per diem at $2\frac{3}{4}$ miles per hour, and an ordinary horse, 121 pounds for 25 miles per diem at $2\frac{1}{2}$ miles per hour.

As the speed of a horse increases his power of draught diminishes very rapidly, until he can only move his own weight.

The following table shows the results obtained by different authors; those of Tredgold being for six hours' daily labor, and those of Wood for ten hours:

| Velocity. Miles per hour. | Tests of draught according to Leslie. | Tredgold. | Wood. |
|---|---|---|---|
| 2 | 100 | 166 | 125 |
| 3 | 81 | 125 | 83 |
| 4 | 64 | 83 | 62 |
| 5 | 49 | 42 | 52 |
| 6 | 36 | — | 42 |
| 7 | 25 | — | 36 |
| 8 | 16 | — | 31 |
| 9 | 9 | — | 28 |
| 10 | 4 | — | 25 |

From the above table, it appears that, according to Wood, at 4 miles per hour a horse can only draw half his load at 2 miles; at 8 miles, only a quarter, etc.

Sir John Macniel estimates his power at 60 lbs., moved 8 miles per diem at same velocity (Gillespie). Wood's Practical Treatise on Railroads contains an interesting chapter on horse-power. He made many experiments. He quotes an interesting memorial to the House of Commons, May 3, 1830, from the proprietors of various (33) stage coaches running out of Liverpool, employing 709 horses. These horses traveled an average distance of 13 miles daily, at a speed not exceeding 10 miles per hour, and the stock had to be renewed every *three years*.

Tredgold assigned 37 pounds as the power that a horse should exert over a distance of 10 miles in a day at a velocity of 10 miles per hour, or one hours' work. This was founded upon his experiments on stage coach horses. They endured this service only three years.

The speed of North Chicago City railway cars is 6 miles per hour, including stoppages, and the average time of service is reckoned at five years for each horse, traveling upon selected cobble stone pavement. Before the cobble stone was adopted the average railway service was four years per horse. The chief street railways of the United States estimate the railroad life of their horses at from three to five years.

May 17th, 1881, I had the honor of addressing you on "The Best Pavement

for Horse Railroad Tracks." Permit me to quote from that paper. "I recently made the following tests of the force required to start car 110 of the North Chicago City Railway Co., and to keep it in motion after it was under way, using a Fairbanks dynamometer. The track has a grade of two-tenths of a foot per hundred. (This grade is up and down, changing, say, each 250 lineal feet, and is compensated, as the observations were taken upon up and down grades.) The track was not free from sand. Between Chicago Avenue and North Avenue, on Clark, Division and Clybourn Avenues, 88 tests with an average of 14.8 passengers, weighing (estimated at 140 lbs.), with car, 6,772 lbs. The force required to keep the car in motion at an average speed of five miles per hour, including stops, averaged 109.5 lbs., or per ton, 32.3 lbs. This is on an old, worn-out iron rail. Between Chicago Avenue and Madison Street, on Clark, on new steel rail, 53 tests, with an average of 20.9 passengers, gave 59.8 lbs. as the force required to keep the car in motion. This is an average of 15.6 lbs. per ton. The car made 17 starts on this track with an average of 18.7 passengers. Average force exerted to start, 426.5 lbs. Average per ton, 116.5 lbs. On the first mentioned track, 30 tests, with an average of 18.1 passengers, gave an average force of 487 lbs.; average per ton, 134.6 lbs.

Recapitulated, the force exerted per ton was, in pounds:

On good track, to start, 116.5;
to keep in motion, 15.6.
On bad track, to start, 134.6;
to keep in motion, 32.3.

These tests indicate the great loss of power entailed by bad track, and also the great loss in starting; and the better the track the greater the relative loss in starting. On the poor track 134.6 lbs. per ton was exerted to start, and this is 4.1 times the force required to keep the car in motion. On good track 116.5 pounds was the force required to start, but this is 7.1 times the force required to keep the car in motion.

Upon the North Chicago Citry Railway the average weight of car and its load is 7,740 pounds, or in short tons, 3.87. Passengers averaged at 140 pounds. Our track is now all good. The average force, therefore, exerted in propelling one car is $3.87 \times 15.6 = 60.372$ pounds when the car is in motion, and $3.87 \times 116.5 = 450.855$ pounds force to start. The horses average 137.97 minutes service per diem. One hundred and three tests upon 17 different cars, open and close, on various lines, with different drivers, made by me on different days and hours, give the following average for the horses: Time consumed in stopping, during which no power is exerted by the horse, 13.22 minutes. Time from starting until average speed is reached, 7.88 minutes.

Now, the horses average as per above 137.97 minutes daily service.

Deducting time they are not exerting force, 13.22 minutes daily service.

Leaves actual work, 124.75 minutes daily service.

Of this power is exerted to maintain motion, 116.87 minutes daily service.

And extra power is exerted during 7.88 minutes daily service.

The horse-power, therefore, exerted in propelling a North Chicago railroad car with its average load by a team in its average day's work is:

$$\frac{450.855 \times 311.5 \times 7.88}{33.000} = 33.53 \text{ H. P.}$$

starting.

$$\frac{60.372 \times 623 \times 116.87}{33000} = 133.22 \text{ H. P.}$$

maintaining motion.

Total, 166.75 H. P.

This is used during 137.97 minutes, average per minute, 1.208 H. P. per team; or for each horse, 604 H. P.

Upon a poor track my previously quoted experiments show that this power would be about doubled, or 2.4 H. P. would be used per average car. About $\frac{1}{5}$ of the horse power is used in starting the car (20.1 per cent.). Mr. Angus Sinclair experimented upon the Third Avenue Elevated Railroad, New York, and estimated that the average pull on the draw-bar was five times greater than it would have been if the motion of the train could have been continuous. See *National Car-Builder*.

A. M. Wellington found, by his experiments, that the initial friction in starting trains of loaded cars was 5.47 times that required to keep them in motion at a speed of 10 to 15 miles per hour. See

Trans. A. S. C. E., December, 1884. Charles E. Emory, Ph. D., found 11.8 pounds per ton of 2,000 pounds to be the resistance on straight and level track in New York. This is less than my average, but his tests were probably made on a center-bearing rail, the usual rail in New York, and this we know offers less resistance to progress, as the head is comparatively clean, while the step-rail head upon which I experimented was *level with the adjoining outside pavement*, and consequently covered more or less with sand and dirt.

D. K. Clarke, in his work on tramways, states that H. P. Holt found the resistance per gross ton on straight, level track varied from 15 to 40 lbs.; Henry Hughes, 26 lbs.—often much more, occasionally less; M. Tresca, 22.4 lbs. per ton. Subsequently M. Tresca removed two flanged wheels on one side of the car, and then found the resistance 15.25 lbs. Mr. Clarke assumes 20 lbs. per ton, and says at times it is 40 lbs. per ton. "An average of 30 lbs. per ton may be taken for the calculation of the ordinary tractive force." In his second volume he states: "The average resistance (30 lbs. per ton), already in the first volume adopted for calculation, may be re-adopted, although an occasional maximum of 60 lbs. per ton may be reached, and, on the contrary, a minimum of 15 lbs. per ton when the rails are wet and clean, straight and new.

Mr. Clarke's remarks refer to grooved rails, which offer greater resistance than the step rail. General Gilmore estimates this resistance at $16\frac{2}{3}$ lbs. per short ton with track in average condition for United States. Mr. C. B. Holmes, President and Superintendent Chicago City Railway, stated that his cable railway required for ordinary operations, engines of 477 horse-power; of that it took 389 horse-power to move the cable and machinery. Eighty-eight horse-power ($18\frac{1}{2}$ per cent.) was used for the propulsion of 240 cars, weighing 6,000 lbs. each, and carrying each 5,00 lbs. of passengers. The average speed was 9 miles per hour, or 792 feet per minute. This statement would indicate that only $\frac{88}{240}$=.367 horse-power per car was required, while my experiments would give: as 3.87 (my average load) is to 5.5 (his average load), so is 1.208 horse-power (used by me) to 1.71 horse-power required.

There must have been some mistake in his test, for .367 horse-power=12,111 foot-pounds. As his speed is 792 feet per minute, the tractive force exerted would be only 15.29 pounds for 5.5 tons, a resistance of less than 3 pounds per ton (2.78 pounds), which is impossible upon a step rail.

Our fellow-member, D. J. Miller, M.E., while employed upon the above mentioned cable railway, made experiments upon the horse-power used. He found that at an average speed of 6.85 miles per hour or 602.8 feet per minute, 1 horse-power was required for each ton of cable and machinery and .2 of a horse-power for each ton of car and its passengers. For my average load of 3.87 tons, this would equal .774 horse-power, instead of 1 2 horse-power as estimated by me. Mr. Miller's .2 horse-power=6,600 foot pounds. His average speed being 602.8 feet per minute, his resistance to traction could have been only 10.95 pounds, including starting the cars. This is 3.94 times the resistance found by Mr. Holmes, but nearly 30 per cent. less than my experiments would indicate. Mr. Miller, however, *assumed* the weight of passengers, having no count of their number, and must have overestimated the load and experimented with the track unusally clean. My average of 15.6 pounds per ton, agreeing so nearly with that of M. Tresca, 15.25, as above quoted, confirms my opinion that it cannot be far wrong. While it is true that M. Tresca's experiment quoted was with only one flanged wheel upon each axle, yet that wheel traveled in a groove, and the resistance could not vary much from my two flanged wheels not in a groove. The car wheels in Chicago are 30 inches in diameter. The horses of the North Chicago Railway weigh about 1,100 lbs. each. The speed at which they travel upon the road averages 623 feet per minute or 7.08 miles per hour. Their average horse power developed being each .604 horse-power equals 19.932 foot-pounds. Divided by 623, the distance per minute, gives 31.99 lbs. tractive force. Leslie's estimate at 7 miles per hour was 25 lbs. Wood's estimate was 36 lbs., at the same speed.

Our horses work daily 2 hours 17.97 minutes, but *seven* days in the week, unless prevented by some unforeseen cause.

I have neglected extra resistance caused by curves, because our lines are chiefly tangents, and it is very difficult to measure the force exerted upon curves, for it varies greatly between 400 and 1,000 lbs., upon the dynamometer with the same car and load. My tests were so unsatisfactory upon curves that I have thought it best to omit them entirely. Then, too, the horse walks around the curve, and the lessened speed in a measure offsets the increased resistance.

The greatest exertion of force upon a tangent during my dynamometer experiments occurred in starting a loaded car. It was 1,500 lbs. average per ton 283.5 lbs. Passing through some slush, caused by snow thrown upon the track, it equaled 75.6 lbs. per ton.

In estimating for any independent motor to propel a street car upon the North Chicago Railway, I would take the maximum load and resistance. I have known of 120 passengers upon an open car. Averaging them at 140 lbs. each, equals 16,800 lbs.; car, 4,800 lbs.; total, 21,600 lbs., or 10.8 short tons. Speed in starting, 0 to 623 feet per minute; average, $311.5.\frac{10.8 \text{ tons} \times 311.5 \text{ feet} \times 283.5 \text{ lbs.}}{33.000} =$ 28.9 horse-power required; a small portion of this power would be constantly employed, but it must be in reserve. With the electric or cable system no such allowance would be required, for the reason that this excess of power is only needed to *start* the car, and my experiments indicate that the car is starting only one-seventeenth of the time, while it requires no power one tenth of the time. For each 17 cars upon a line, therefore, it would be necessary to furnish power to *start one* car and to maintain sixteen cars in motion, less the power when stationary, as it is not probable, nor is it necessary, that all should start at the same instant.

During my experiments the car stopped upon an average each 1,178 lineal feet. We stop only at street intersections, or at the center of blocks more than 500 feet long.

The following returns are taken from the Sixteenth Annual Report of the Massachusetts Board of Railroad Commissioners:

| Name of Railroad. | Number of horses owned. | Number of Miles Run. | Number of Passengers Carried. | Average No. of Passengers per Round Trip. |
|---|---|---|---|---|
| Highland | 909 | 1,670,347 | 10,452,441 | 43 |
| Lynn & Boston | 608 | 1,052,296 | 6,364,009 | 50 |
| Metropolitan | 3183 | 6,046,879 | 34,574,135 | 38 |
| Middlesex | 601 | 1,047,411 | 7,099,892 | 45 |
| South Boston | 857 | 1,470,261 | 9,706,299 | 41 |
| Total | 6158 | 11,287,196 | 68,196,776 | Average. 43.4 |

From the above it appears that the stable average daily distance traveled by the above horses equals 10.04 miles, found by dividing total number of miles run by total number of horses, and this by 365 and multiplying by $2\frac{11,287,196 \times 2}{6158 \times 365} =$ 10.04.

The average number of passengers for these five railroads per round trip being 43.4 per single trip, equals 21.7. Averaging them at 140 pounds, equals 3,038 pounds. Add weight of car, 4,800 pounds equals 7,838 pounds, or 3,919 short tons, which is in excess of my average load of 3.87 tons.

It is fair to assume that these horses are worked to the best advantage and that this is all that can be expected of a horse upon a tramway.

The stables of the North Chicago Railway are located at or near one end of each line. The horses are in excellent condition. Their mileage could not be

increased, even if it was thought desirable, unless they were changed from car to car upon the road, and this would cause delay and inconvenience. They now make two round trips and could not make more without adding 50 per cent. to the distance they now travel or changing upon the road.

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## FLAME CONTACT—NEW DEPARTURE IN WATER HEATING.

By THOS. FLETCHER, F.C.S.

From "English Mechanic and World of Science."

It is my intention to prove to you, on theoretical grounds, and also by experimental demonstration, in such a manner as will admit of no possible doubt, that the present accepted system of water heating, by gaseous or other fuel, is a very imperfect means for an end, and is, both in theory and practice, essentially faulty. My statements may appear bold, but I come prepared to prove them in a manner which I think none of you will question, as the matter admits of the simplest demonstration. I will, in the first place, boil a specified quantity of water in a flat-bottomed vessel of copper; the time required to boil this you will be able to take for yourselves, as the result will be visible by the discharge of a strong jet of steam from the boiler. I will then take another copper boiler of the same form, but with only one-half the surface to give up its heat to the water, and will in this vessel boil the same quantity of water with the same burner in a little over one-half the time, thus about doubling the efficiency of the burner, and increasing the effective duty of the heating surface nearly fourfold, by getting almost double the work from one-half the surface. The subject is a comparatively new one, and my experiments are far from complete on all points; but they are sufficiently so to prove my case fully. As no doubt you are all aware, it is not possible to obtain flame contact with any cold, or comparatively cold, surface. This is readily proved by placing a vessel of water with a perfectly flat bottom over an atmospheric gas burner; if the eye is placed on a level with the bottom of the vessel a clear space will be seen between it and the flame. I cannot show this space on a lecture table to an audience; but I can prove its existence by pasting a paper label on the bottom of one of the boilers, and exposing this to the direct impact of a powerful burner during the time the water is being boiled, and you will see that it comes out perfectly clean and uncolored. Now, it is well known that paper becomes charred at a temperature of about 400° F., and the fact that my test paper is not charred proves that it has not been exposed to this temperature, the flame being in fact extinguished by the cooling power of the water in the vessel. I need hardly remind you that the speed with which convected or conducted heat is absorbed by any body is in direct ratio to the difference between its own temperature and that of the source of heat in absolute contact with it; and, therefore, as the source of the heat taken up by the vessel is nothing but unburnt gases, at a temperature below 400° F., the rate of absorption cannot, under any circumstances, be great, and the usual practice is to compensate for this inefficiency by an enormous extension of surface in contact with the water, which extension I will prove to you is quite unnecessary. You will see I have here a copper vessel with a number of solid copper rods depending from the lower surface; each rod passes through into the water space and is flattened into a broad head, which gives up its heat rapidly to the water. My theory can be stated in a few words: "The lower ends of the rods, not being in close communication with the water, can, and do attain a temperature sufficiently high to admit of direct flame contact, and as their efficiency, like that of the water surface, depends on the difference between their own temperature and that of the source of heat in absolute

contact with them, we must, if my theory is correct, obtain a far greater duty from them. I do not wish you to take anything for granted; and although the surface of the rods, being vertical, can only be calculated for evaporating power at one-half that of a horizontal surface, as is usual in boiler practice, my margin of increased duty is so great that I can afford to ignore this, and to take the whole at what its value would be as horizontal surface, and still obtain a duty 50 per cent. greater from a surface which is the same in area as the flat-bottomed vessel on the fireside, but having only one-third the surface area in contact with the water. I do not, of course, profess to obtain more heat from the fuel than it contains, but simply to utilise that heat to the fullest possible extent by the use of heating surfaces beyond comparison smaller than what have been considered necessary, and to prove not only that the heating surface can be concentrated in a very small area, but also that its efficiency can be greatly increased by preventing close water contact, and so permitting combustion in complete contact with a part of the heating surface. I will now boil 40 oz. of water in this flat-bottomed copper vessel, and, as you will see, sharp boiling begins in three minutes fifteen seconds from the time the gas is lighted. The small quantity of steam evolved before this time is of no importance, being caused partly by the air driven off from the water and partly from local boiling at the edges of the vessel owing to imperfect circulation. On the bottom of this vessel is pasted a paper label, which you will see is untouched by the flame owing to the fact that no flame can exist in contact with a cold surface. It may be thought that, owing to the rapid conducting power of copper, the paper cannot get hot enough to char. This is quite a mistake, as I will show you by a very curious experiment. I will hold a small plate of copper in the flame for a few seconds, and will then hold it against the paper. You will see that, although the copper must of necessity be at a temperature not exceeding that of the flame, it readily chars the paper. We can, by a modification of this experiment, measure the depth of the flameless space, as the copper, if placed against the paper before it has time to be previously heated, will, if not thicker than 1-40 inch, never become hot enough to discolor the paper, showing that the flame and source of heat must be below the level of a plate of metal this thickness. In repeating this experiment I must caution you to use flour paste, not gum, which is liable to swell and force the paper past the limit of the flameless space, and also to allow the paste to dry before applying the flame, as the steam formed by the wet paste is liable also to lift the paper away and force it into the flame. I will now take this vessel, which has only one-half the surface in contact with the water, the lower part being covered with copper rods, 3-16 in. diameter, $\frac{1}{2}$ in. centers apart and $1\frac{1}{2}$ in. long, and you will see that with the same burner as before, under precisely the same conditions, sharp boiling takes place in 1 minute 50 seconds, being only 13 seconds more than half the time required to produce the same result with the same quantity of water as in the previous experiment. Although the water surface in contact with the source of heat is only one-half that of the first vessel and the burner is the same, we can see the difference not only in the time required to boil the 40 oz. of water. but also in the much greater force and volume of steam evolved when boiling does occur. With reference to the form and proportions of the conducting rods, these can only be obtained by direct experiment in each case for each distinct purpose. The conducting power of a metallic rod is limited, and the higher the temperature of the source of heat, the shorter will the rods need to be, so as to insure the free ends being below a red heat, and so prevent oxidation and wasting. There are also other reasons which limit the proportions of the rods, such as liability to choke with dirt and difficulty of cleaning, and also risk of mechanical injury in such cases as ordinary kettles or pans—all these requirements need to be met by different forms and strengths of rods to insure permanent service, and, as you will see further on, by substituting in some cases a different form and type of heat conductor. To prove my theory as to the greater efficiency of the surface of the rods in contact with the flame as against that in direct contact with the water, I have an-

other smaller vessel which, including the rods, has the same total surface in contact with the flame, but only one-third the water surface as compared with the first experiment. Using again the same quantity of water and the same burner, we get sharp boiling in 2 minutes 10 seconds, being an increase of duty of 50 per cent., with the same surface exposed to the flame. The rods in the last experiment form two-thirds of the total heating surface, and if we take, as I think for some careful experiments we may safely do, one-half the length of the rods to be at a temperature which will admit of direct flame contact, we have here the extraordinary result that flame contact with one-third of the heating surface increases the total fuel duty on a limited area 50 per cent. This really means that the area in contact with the flame is something like six times as efficient as the other. In laboratory experiments it is necessary not only to get your result, but to prove your result is correct, and the proof of the theory admits of ready demonstration in your own laboratories, although it is unfit for a lecture experiment, at all events in the only form I have tested it. If you will take two ordinary metal ladles for melting lead, cover the lower part of one of these with the projecting rods or studs and leave the other plain, you will find on melting a specified quantity of metal in each that the difference in duty between the two is very small. The slight increase may be fully accounted for by the difference in the available heating surface reducing the amount of waste heat passing away, and this proves that flame contact, and therefore quick absorption of heat, takes place on plain surfaces as soon as these are above a certain temperature which, in a metal ladle, very soon occurs. What the temperature is which admits of flame contact I have, as yet, not been able to test thoroughly, and it will need some consideration how the determination of this is to be correctly made; at the same time it is a question in physics which should be capable of being answered. Let us now take the other side of the question. If the efficiency of a surface depends on flame contact, there must of course be flame, or at least gases of an extremely high temperature, and we therefore cannot expect this extraordinary increase of efficiency in any part of our boiler except where flame exists, and if these projections are placed in a boiler, anywhere except in contact with flame, their efficiency must be reduced to that of ordinary heating surface. They are, of course, useful, but only in the same way as ordinary flue surface. When we come to boilers for raising steam, which have to stand high pressures, we come to other difficulties of a very serious nature, which require special provision to overcome them. To put such rods as I have referred to in a boiler-plate necessitates the plate being drilled all over with holes, causing a dangerous source of weakness, as the rods cannot be used as stays; further than this, they would render really efficient examination a matter of extreme difficulty, and would be liable to give rise to frequent and almost incurable leakages; but there is, fortunately, a very simple way to overcome this difficulty. I have found that rods or points, such as I have described, are not necessary, and that the same results can be obtained by webs or angle-ribs rolled in the plates. My experiments in this direction are not complete, and at present they tend to the conclusion that circular webs, which would be of the greatest efficiency in strengthening the flues, are not so efficient for heating as webs running lengthways with the flue, and in a line with the direction of the flame. This point is one which I am at present engaged in testing with experimental boilers of the Cornish and Lancashire type, and, as we have in gas a fuel which renders every assistance to the experiment, it will not take long to prove the comparative results obtained by the two different forms of web. Those of you who have steam boilers will, no doubt, know the great liability to cracking at the rivet holes in those parts where the plates are double; this cracking, so far as my own limited experience goes, being usually, if not always, on the fire side, where the end of the plate is not in direct contact with the water, where it is, in fact, under the conditions of one of the proposed webs. I think we may safely come to the conclusion that this cracking is caused by the great comparative expansion and contraction of the edge of the plate in contact with

the fire, and it will probably be found that if the plates are covered with webs, the whole of the surface of the plates will be kept at a higher and more uniform temperature, and the tendency to crack at the rivet-holes will be reduced. This is a question not entirely of theory, but needs to be tested in actual practice. There is another point of importance in boilers of the locomotive class, and those in which a very high temperature is kept in the fire-box, and this is the necessity of determining by direct experiment the speed with which heat can safely be conducted to the water without causing the evolution of steam to be so rapid as to prevent the water remaining in contact with the plates, and also whether the steam will or will not carry mechanically with it so much water as to make it objectionably wet, and cause priming and loss of work by water being carried into the cylinders. I have observed, in the open boilers I use, that when sufficient heat is applied to evaporate one cubic foot of water per hour from one square foot of boiler surface, the bulk of the water in the vessel is about doubled, and that the water holds permanently in suspension a bulk of steam equal to itself. I have, as yet, not had sufficient experience to say anything positively as to the formation or adhesion of scale on such surfaces as I refer to, but the whole of my experimental boilers have, up to the present, remained bright and clean on the water surface, being distinctly cleaner than the boiler used with ordinary flat surfaces. It is, I believe, generally acknowledged that quick heating and rapid circulation prevent, to some extent, the formation of hard scale, and this is in perfect accord with the results of my experiments. The experiment which I have shown you, I think, demonstrate beyond all question that the steaming power of boilers in limited spaces, such as our sea-going ships, can be greatly increased; and when we consider how valuable space is on board ship, the matter is one worthy of serious study and experiment. It may be well to mention that some applications of this theory are already patented. I will now show you as a matter of interest in the application of coal gas as a fuel, how quickly a small quantity of water can be boiled by a kettle constructed on the principle I have described, and to make the experiment a practical one I will use a heavy and strongly-made copper kettle which weighs 6½ lbs., and will hold when full one gallon. In this kettle I will boil a pint of water, and, as you see, rapid boiling takes place in 50 seconds. The same result could be attained in a light and specially made kettle in 30 seconds, but the experiment would not be a fair practical one, as the vessel used would not be fit for hard daily service, and I have therefore limited myself to what can be done in actual daily work rather than laboratory results, which, however interesting they may be, would not be a fair example of the apparatus in actual use at present.

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## CHOLERA IN ITS RELATION TO WATER SUPPLY.

By GEORGE HIGGIN.

From "Nature."

The epidemic of Asiatic cholera, which has been raging in Spain during the last two years, and which appears even yet to be lurking in some portions of that peninsula, has furnished some interesting data as regards its connection with water supply, to which it would be wise in us to direct our attention, not only from the interesting nature of the facts as such, but also because it is not improbable that ere the disease quits Europe it may visit our own shores.

Broadly speaking, it would appear that in Spain this formidable disease never became truly epidemic or dangerous in any city in which there was a pure and good supply of water, and proper means were taken to guard against the sources being polluted by any of the specific choleraic poison.

In support of this idea I would desire to call attention to the cities of Toledo, Seville, Malaga, and Madrid, in contradistinction to such places as Aranjuez, Saragossa, Granada, and Valencia. I will commence with Madrid. This city, whose population at the last census was 397,816, suffered very severely, indeed, under the last epidemic of 1865, when during several days immediately following a very severe thunderstorm, the number of cases varied from 800 to 1,200 per day. The first invasion of last year took place in Madrid on May 20, and the disease ran its course during the whole of the summer, gradually disappearing towards the end of the month of September. The total number of cases during the whole of the period was 2,207, and the deaths 1,366. The total number of cases, therefore, during the five months that the disease never abandoned the city was barely more than what occurred during two days only of the epidemic of 1865, being little more than $\frac{1}{2}$ per cent. of the population. I think, therefore, we may safely say that the disease never assumed a truly epidemic form. The greatest number of cases, as was to be expected, took place during the months of July and August; the first notable increase took place on July 25, and the first notable decrease on August 13.

In connection with this it is interesting to note that Madrid was subject to severe thunderstorms during the latter end of July, and that 119 millimeters of rain fell during the month. These storms began on the 13th, and were especially severe on the 23d, 24th, 26th, 27th, and 31st, the first notable rise in the cases of cholera occurring between the 25th and 28th. As a general rule, no rain falls in Madrid in July, and the occurrence of these severe thunderstorms and heavy falls of rain was quite phenomenal.

The new water supply from the Guadarama Mountains was completed shortly before 1865, and the greater part of the drainage was also finished; but at that time the new water supply had scarcely come into use, the large majority of the houses being supplied from the old fountains which existed in various parts of the city. During the last twenty years the use of the Lozoya water has become very general, and an ample supply has been provided for washing the streets and flushing the sewers.

Madrid is now well drained; the sewers are built upon the Paris model, and are not what an English engineer would consider as a good type for self-cleansing purposes, but the fall is, in almost every case, very great, and it is not probable that there can be any collection of fœcal matter at any point. The connection of the street gullies with the main sewers is made without any trap, and good ventilation is thus provided. As regards the outfall of these sewers, nothing satisfactory can be said. The mouths of the main sewers, which are seven in number, all discharge on the southern side, between the station of the Saragossa Railway and that of the Northern.

The question of the proper disposal of the sewage in Madrid, as in London, has never been decided, and pending this decision the sewers were completed only as far as the outlying houses of the city, and the sewage was then allowed to find its way down to the Manzanares, in the best way it could. During the time the question has been awaiting a solution the town has extended, and houses have been built along the course of these open sewers. As might have been expected, the first serious outbreak of cholera occurred about these spots, the original germ of the disease having been imported from the neighborhood of Valencia, where the cholera was then raging.

The existence of the disease having been established beyond doubt, one of the first acts of the Municipality was to attend to the water supply. There existed 11 ancient sources, which supplied 85 taps or fountains, 22 of which were public ones, at which water-carriers were allowed to fill their barrels, and the remaining 63 belonged to groups of houses. In spite of the excellent supply brought in from the Lozoya, these old sources were still a good deal used by the inhabitants—many, from old habits, preferring to use the same water which their fathers had used, many not being willing to incur the expense of laying on the new supply. In view of the impossibility of effectually guarding against the possible contamination of so many sources of supply, the Municipality, by decree, on June 18, closed all the old ones, with the ex-

ception of that of La Fuente de la Reina, which supplied five public fountains and four private ones. The Central Government undertook the custody of the Lozoya aqueduct, the Municipality took charge of the Fuente de la Reina. The Lozoya water is drawn from the sources of the River Lozoya in the Guadarama Mountains, some 50 miles to the north of Madrid.

The river takes its rise in the granite formation; the water is excellent, and from the uninhabited condition of the country through which the river flows before the intake, it is not exposed to direct contamination from any specific poison. From the intake to Madrid the water is conducted by a series of magnificent works, partly covered, partly uncovered, to Madrid, where it is received in covered reservoirs before being distributed in the city; the service is continuous, no cisterns being used. During the whole time of the existence of cholera in the city the uncovered portion of the aqueduct was patroled by armed guards, no one being permitted to approach without a special order.

Accompanying the extensive report of Madrid, Don Alberto Bosch, amongst other plates, is an excellent map of the city, showing, by a red dot, the situation of every case of cholera that occurred; they are seen pretty thickly scattered about the uncovered exits of the sewers, and on both sides of the River Manzanares, which is, in fact, in summer, an open sewer, and in the lower portion of the city overlooking the river, and there is scarcely any part of the town where a dot is not to be found; but, with the exception of the points mentioned, the cases occurring in the remainder of the town seem to be all isolated ones; in extremely few cases do two dots occur together, showing that the disease was more of a sporadic than of an epidemic character.

Now let us take the case of Toledo. This ancient capital of Spain is certainly not a city that could be taken as a model of sanitary arrangements; on the contrary, it seem to be admirably adapted to form a good nest for any wandering epidemic, and yet, although the cholera entered it in the summer of 1884, and did not finally leave it till the autumn of 1885, the total number of cases, according to official returns, did not exceed 200, of which about one-half were fatal. The population of Toledo is over 20,000, so that the percentage of choleraic disease was only about 1 per cent. of the population for the two seasons.

Toledo was supplied with water from the river Tagus, which flows round the city, the water being lifted by pumps. Above Toledo on the same river, is situated Aranjuez, and above Aranjuez again, on the Manzanares, which is a feeder of the Tagus, is situated Madrid, in both of which towns the cholera existed in 1885, being unusually severe in Aranjuez. The Governor of the province, recognizing the suspicious character of the water, stopped the pumps, and obliged the inhabitants to send for their drinking water to a distant spring; he even forbade anyone to bathe or wash clothes in the river. The measure was a strong one, but it saved the city.

Let us next take Seville. Seville is an important city, the third in rank in Spain; it contains, according to the census of 1877, 134,318 inhabitants; it has, strictly speaking no drainage; a few ancient sewers exist for carrying off the rainwater from the lower portion of the city, but sewerage for houses does not exist. The sewage goes into cesspools, which are, in most cases, situated just outside the house, and under the street; the inhabitants are extremely cleanly in their habits, and the outsides of their dwellings are constantly whitewashed, but it is not a healthy city—typhoid fever is endemic, and the death rate rises in some parishes to 35 per mil.

Seville is situated on the river Guadalquiver, of which the rivers Darro and Genil, that flow through Granada, are feeders; as regards its water-supply, one suburb of the city, called Triana, containing about 30,000 inhabitants, is situated on the western side of the river. This portion is almost entirely inhabited by the poorer, class, and they drink generally the water of the river.

The rest of the town is supplied from an ancient Roman or Moorish aqueduct, the water being brought from an underground spring near the town of Alcala, about nine miles to the east of Seville; this water is carried by a tunnel about two miles in length under the town of Alcala; it is then carried in a covered conduit to

within a short distance of Seville, and from thence by an aqueduct made by the old Moors. The water is excellent.

An English company has quite lately erected engines at Alcala, by means of which they pump up to a covered reservoir above the town, the water from two other springs, situated also at Alcala, but on the opposite side of the river Guadaira, which flows past the town. This water is carried from the reservoir into the town by iron pipes, and distributed under considerable pressure; in character it is pure and excellent; the springs rise from the base of the sandstone at a short distance from the engine house, and are carried across the river by an iron pipe. The cholera broke out in Granada on July 14, 1885, but already on June 14 of the same year the authorities of Seville, by way of prevision, had prohibited the use of any water from the river, either for dietetic or other purposes; had authorized the English company to lay a temporary pipe across the bridge which connected the city with the Triana suburb, and had opened a number of free taps from which the inhabitants of this suburb could draw the new water.

The old Moorish supply was scarcely susceptible of contamination, as the conduit was covered for the greater part of way, and where it ran over the aqueduct no one but the Municipal guards had ever been allowed to pass; guards, however were stationed day and night on the springs from which the English company derived their water, and no one was allowed to approach them without permis sion.

The cholera raged fearfully in Granada during the months of July, August, and September; it descended the River Genil, which runs through Granada, and attacked the towns of Herera, Ecija, and others in the province of Seville. It broke out also at Cordova and other towns on the Guadalquivir, of which the Genil is an affluent, and it broke out in Palma, Utrera, Puerto Real, Puerto Santa Maria, and Cadiz, forming a circle around Seville, but the city itself escaped almost completely. Towards the end of September nine cases occurred in one quarter of the city, of which seven were fatal, but the disease did not spread; none of the five houses in which these cases occurred were connected on to the water supply, and it is possible they may have used well or river water, although this is not known. Jerez, which lies about half-way between Seville and Cadiz, and close to the town of Puerto Santa Maria, which was attacked by cholera, escaped also from the disease. This town possesses a very excellent water-supply, brought down some few years ago from a spring in the mountains by a native company, at a cost of £300,000.

Malaga has a population of 115,882. This city is in even a worse sanitary condition than Seville as regards its drainage, and a great deal worse as regards its cleanliness. In the old portion of the town the streets are narrow, unventilated, and intolerably filthy; the climate in summer is almost tropical.

It is difficult to obtain reliable data as to the cases of cholera in Malaga, as attempts were made to prove that no real cholera existed in Malaga; but there can be no doubt but that from June to September the cholera did exist, and it is probable that during the whole of the summer there occurred some 200 or 300 real cases of Asiatic cholera. But the disease never became epidemic, although, to all appearances the city offered a most excellent medium for the propagation of the disease, and on all former visitations had suffered very severely. But Malaga, during the last few years, has been provided with an excellent water-supply drawn from some springs situated at Torremolinas, on the coast to the westward of the city, and piped from thence into the city; and although the precautions adopted were not so complete as those at Seville, yet a more or less successful attempt was made to prevent the use of any other water than that brought from Torremolinas.

We have now examined the case of the few towns in Spain that possess a pure supply of water drawn from springs not liable to any specific contamination, and we have seen that in all cases where such a supply existed, the cholera, although present in all of them, never made any headway, or became truly epidemic, although in every case, except that of Madrid, there was no proper drainage, and the sanitary conditions were in many cases as bad as they could be.

Let us now look on the other side of the picture. We will commence with Granada—population 76,005. As regards its sanitary arrangements, this city is on a par with Malaga; about one-tenth of the town is drained, but the sewers are of a very inferior class. The city is supplied with water by canals derived from the Genil and Darro, the two rivers which serve to irrigate the magnificent plain which speads around it. A small portion is supplied from a spring called La Fuente Grande de Alfacar. The canals are uncovered and exposed to all kinds of contamination.

Through the streets the water is conducted in earthenware pipes, after the style of the Moors; many of the pipes are the original ones put down by these people before the conquest of the city by Ferdinand and Isabella. The cholera broke out about the middle of July. It is supposed to have first been brought in by some laborers who had arrived from Murcia, where the cholera was raging. It spread with frightful rapidity, and by the middle of August the official number of cases reported was over 450 per day. It died out, or rather wore itself out, about the middle of September. The total official returns give a total of 6,471 cases, and 5,093 deaths, but in the city itself these returns are said to be much under-estimated; some, indeed, say the numbers should be doubled.

No attempt was made, as was done at Toledo with such excellent results, to suppress the old water supply, and the epidemic took in a short time such alarming proportions that the local authorities were completely paralyzed. It was difficult to carry on the interment of the bodies, and at one time from 400 to 500 corpses were lying piled up in the cemetery awaiting interment.

The course of the cholera may be followed down the rivers Darro and Genil, the infected waters carrying death wherever they were used for drinking purpurposes.

Murcia — population 91,805 — from which the cholera was imported into Granada, suffered heavily also. It was carried into the plains of Murcia by the waters of the river Segura, from the baths of Archena, and it was imported into Archena by some invalid soldiers who were sent to the baths from the infected district around Valencia. The plain of Murcia is irrigated by the waters of the Segura, and the disease commenced in this district with the death of a laborer who had drunk the water of one of the irrigation channels. The inhabitants of Murcia and of the plain use principally water from the irrigation canals or from the river; this water is usually stored in large jars similar to those which held Ali Baba and his forty thieves, and among well-to-do people it is customary to keep a year's supply in hand; that is to say, the water is allowed to repose for one year, before use, in a reservoir or "algibe," constructed on purpose, or in some of these large jars sunk up to their necks in the ground; by this means it becomes perfectly clear, cool, and palatable. The poorer classes are, as a matter of course, not able to take these precautions, and have to drink the water from the canals, or after a few days' repose only.

The epidemic raged principally amongst the little cottages scattered thickly over the plain, or garden, as it is called, but the disease never developed itself in Murcia as it did in Granada, and the city itself escaped better than might have been expected. May this not be attributed to the fact that the greater part of the people in the city were drinking water collected in the foregoing year, before the cholera had appeared on the sources of their water supply? And if this be so, may we not anticipate a fresh outbreak this year, if the choleraic poison or germs are capable of outliving a year's repose and darkness?

In reference to water supply and cholera, no case is so instructive as that of Valencia. This city is fairly well drained, as drainage goes in Spain, and as regards cleanliness is certainly in a better situation than Malaga or Granada. The water supply is derived from the river Turia; it is taken from the river near the town of Manises, abut three miles and a-half above Valencia; it is passed through sand filters situated between Manises and Mislata, and is stored in a covered reservoir, from whence it is conducted by iron pipes, a distance of about one mile and a-half into the city.

In one of the interesting letters written by the special correspondent of the *Times* during his tour of inspection of

the cholera districts, a very clear description is given of the track taken by the cholera from its starting point in Alicante, where it had broken out at the latter end of 1884, to Valencia in 1885. During the course of the year 1884, the disease had crossed the frontier of the provinces of Alicante and Valencia, and established itself in Jativa, a somewhat important town, situated on one of the affluents of the Jucar—this and the Turia being the two rivers whose waters are used for the irrigation of the wonderful "Huerta," or Garden of Valencia. During the winter the disease lay dormant, but it broke out in the spring of 1885, and traveled rapidly down the river to Alcira, attacking the various towns situated on the river itself, or on the canals derived from it.

The epidemic was severe at Alcira, but, as the *Times* correspondent suggestively remarked, it ceased so soon as the inhabitants gave up drinking river water, and took their supply from a spring situated at a considerable distance from the town. From Alcira it traveled across the network of canals till it reached the river Turia. The *Times* correspondent says: "It came very near Valencia, and yet never touched the capital till it had worked right around."

At last, in the middle of May, having crossed the water supply of the city and thoroughly infected the river, it attacked the city right royally, and by the end of June the number of cases had risen to 700 daily, out of a population of 143,861. The disease died out in September, having, according to the official accounts, attacked during the four months 4,234 people.

We will now turn to Saragossa. Saragossa, the capital of the ancient kingdom of Aragon, is situated on the right bank of the river Ebro; it contains 84,575 inhabitants, and is an important city. Like most Spanish towns and cities it has no sewers; fœcal matter is collected, as in Seville, in cesspools, which are periodically emptied.

Its principal water supply is derived from the Canal de Aragon, which in its turn draws its supply from the Ebro, near Tudela. This canal was intended principally for navigation, and is now used for this purpose, and also for irrigation. It passes at a short distance above Saragossa, and the town supply, after being drawn from the canal, is stored in reservoirs, and, after depositing its mud, is then passed through charcoal filters. Some of the inhabitants of the city drank the water from an irrigation canal taken from the river Jalon; some used the waters of the Ebro, which flows close past the old walls of the city.

The disease broke out in Saragossa shortly after the middle of July, and the number of cases during the time the epidemic raged was close upon 10,000. The proportion of deaths was small, thanks to the heroic and energetic conduct of the authorities and the people. Some time before the commencement of the disease in the city, a number of small towns on the banks of the Ebro and the Jalon had been attacked by the cholera; there was therefore ample opportunity for the infection of the water-supply. Against such contamination, the only protective measure as regards the general supply was the filtration through charcoal; as regards the Jalon water, there was no protection. This source of supply was, however, ultimately stopped by the authorities, who prevented the water reaching the city, with a notable result as regarded the decrease of the epidemic in the quarter served by them.

It would be interesting to follow out still further the line of inquiry I have adopted, but the examination would be too prolix for the present purpose. The cases I have presented are typical ones; they might be increased *ad libitum*, but I think they are sufficient for my purpose. From an examination of them it would appear as though, in the case of cholera, drainage and sewerage is a secondary subject, the primary one being the water supply. We have seen that the cities of Toledo, Seville, and Malaga, although in bad conditions as regards their sewerage and general sanitary arrangements, yet escaped from any serious attack of cholera, whilst Murcia, Valencia and Saragossa suffered most severely, although in their case the sanitary arrangements were certainly not worse, but if anything better, than the three former cities. But, in the case of the three first-named cities, each one enjoyed a supply of water drawn from springs situated at a distance from the city, and carefully watched and guarded

to prevent any contamination, and the exclusive use of this water was rendered imperative by the authorities.

In the case of Valencia, Saragossa and Murcia, we have a supply drawn from rivers subject to contamination from various sources, against which the only protection was that furnished by the doubtful process of filtration.

There can be no doubt that the cholera attacks in preference those who live under unsanitary conditions, and whose habit of body is by this means prepared to receive the germs of any disease that may be prevalent.

There is no doubt that the virus can be conveyed about from one place to another, like small-pox, typhus, and various other diseases, either by clothes or in the human body, and where it finds a proper medium it will develop itself and extend; but, like these other diseases, it can in these conditions be isolated, fought, and conquered, but without doubt the medium *par excellence* for the spread of cholera-poison is water, and more particularly so when water so infected is used for dietetic purposes.

When it gets possession of the water supply of a city, no bounds can restrain it; there is but one resource, and that is the cutting off of the water.

We do not yet know in what the choleraic poison consists; it is, in all probability, a a micro-organism of some sort which is capable of very rapid development in water, but it cannot be yet said what is the particular micro-organism which produces cholera. The "comma Bacillus," of Koch, has not been accepted by the scientific authorities; on the contrary, very high ones deny altogether its identity with cholera, and assert that it is to be found in the mouth of every healthy person. Whatever the specific germ may be, it is at least doubtful whether any filtration will intercept it; from the experience obtained at Valencia and Saragossa it appears evident that neither sand nor charcoal will do so.

In a paper read recently at the Institute of Civil Engineers, Dr. Percy Frankland asserts that the London Water Companies do, at the present moment, eliminate 96 per cent. of all the micro-organisms in the Thames water by simple filtration through 3 feet of fine sand. This may be so, but it is equally certain that filtration through sand, even at a slow speed indeed, will not eliminate the minute particles suspended in waters of a deltaic character, and which gives such water their peculiar color. If sand is incapable of intercepting these particles, it may also be incapable of intercepting the specific germs or poison that produce cholera in the human body.

Filtration is, at the best, but a doubtful proceeding for the purification of water. It is impossible to control effectually the speed of the filters; they vary at every moment, and although a mean term may be arrived at by taking the area of the filter-beds and the volume of water filtered in the twenty-four hours, yet this really affords no reliable guide as to the actual speed at which the water has passed the filters. It is probable, nay, almost certain, that out of a given quantity of water, no two gallons have passed at the same speed, and it is possible and probable that one-half of the total volume may have passed the filter at double or treble the speed of the rest.

To insure immunity from contamination, the only real and practical method appears to be that of capturing the water at a pure source and conducting and delivering it in such a way as to render it impossible that any specific germ or poison should have obtained access to it. In the matter of cholera, for instance, with the experience of Valencia and Saragossa before us, one cannot feel any confidence in water which is taken from a river liable to so many sources of contamination as is the Thames, and it is at least doubtful whether any system of filtration would be capable of eliminating cholera-poison from such waters. It is extremely probable that simple filtration through sand will not do it.

The very interesting series of letters published by the *Times* on the subject of cholera in Spain, afford much valuable data as to the causes of the disease, or rather as to its mode of propagation. It is unfortunate that the writer seems to have gone out with a preconceived idea that the cause of the propagation of cholera was defective drainage, and consequently to have devoted the greater part of his time to the examination of the sewerage of the various towns he visited, and of their general sanitary arrangements, the water supply being as a

rule relegated to the second place. He appears to be a strong advocate for traps, and not to be aware that the best sanitary authorities of the present day are beginning to doubt very strongly the utility of traps, and to rest their practice rather on the thorough ventilation of sewers, the rapid discharge of their contents, and a complete disconnection between the house drainage and the main sewers.

It is not too late for some scientific investigator to go over the track of the cholera invasion in Spain, to trace the progress of the disease in the towns it visited, and ascertain all the facts connected with their drainage and water supply, and also, what is not less important, examine the conditions of those towns which so far have enjoyed a practical immunity from the epidemic. As much is to be learned from this negative evidence as from the other.

Pending the discovery by scientific men as to the particular germ or poison that creates cholera, such a practical examination as I suggest would be of immense value to us by teaching how the propagation of the disease is principally brought about, and what are the best means of preventing it.

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## ENGINEERING—ITS ACHIEVEMENTS AND ITS REWARD.

By C. W. BUCHHOLZ.

Proceedings of the Engineers' Club of Philadelphia.

Professor Reuleux read, about a year ago, before the Gewerbe-Verein, in Vienna, a very interesting paper, entitled: "Kultur und Technik," of the beginning of which the following is almost a literal translation. He says:

"In taking a broad view over the present condition of culture in this world of ours, we cannot fail to see what an all important influence is exerted by technical skill based upon scientific principles, and as practised in our days. No one can ignore how it has helped us to accomplish incomparably more material progress than was possible to mankind a few hundred years ago—be it in the domain of rapid transportation of passengers, or of heavy cargoes by land or sea; be it in the tunneling of great mountains, in the boring of deep mines, or in the ascending high in the air; be it in sending with lightning rapidity our thoughts around the earth, or in transmitting our voice for hundreds of miles across the country; be it on the one hand to control the mightiest forces and to compel them to do us mechanical service, or be it to utilize, on the other hand, the most subtle processes of nature, elements of the material world so delicate and fine that they almost escape ordinary observation.

"Everywhere in our modern life, here, around us, upon us, with us, and near us, wherever we go, technical science has become our busy servant and companion, in ever restless activity, the influence of which we never really appreciate until we have to do without its assistance for ever so short a period. All this is well known, and has become almost commonplace, yet it appears to me that it is not so thoroughly established as it should be among educated people, and not even in the narrower circles of men of technical training.

"The world does not as yet look upon technical science by any means as the great lever and factor of culture, which it really is."

The Professor then goes on to hint at the probable cause why this is so, but he does not advance any definite reasons, and he refuses to deliver a panegyric on "Technic," or "Engineering," as I will call it hereafter, for the latter nowadays embraces nearly all the first implies; and he declines to demolish by his facts and logic those who refuse to give to the arts and sciences the long-hoped-for acknowledgment. He, however, very ably proves and shows what the true position of engineering is in the universal activity towards the solution of the great prob

lem of culture, and he very clearly points to the methods it has ever pursued since the earliest times.

Now, I would like more particularly to draw the attention of the Club to the very question the Professor leaves unanswered, but which seems to me to be of the greatest importance to every man of mechanical training, to every engineer who has selected his profession, not in order to maintain a precarious and humble existence, but rather to rise above his fellowmen and become a distinguished member of society; a leader of progress as well as the pioneer, corresponding to his higher education and to his responsible and arduous duties. Why is it that in every highly civilized community the men graduating from the classical departments of universities generally at once take a higher social position than those coming from polytechnic schools? Why is not the degree of Doctor conferred upon the engineer as well as upon the lawyer, the physician, and the preacher? Why is it that all other professions have far outstripped him in their social and political influence? Surely the engineer has done much more for the general development of the resources of our mother earth and for the progress of mankind, and has accomplished much more towards making "life worth living" than any other profession, be it ever so classical or learned in the laws, in medicine, or theology.

Leaving out of consideration the temples and palaces, and public buildings erected during the very earliest periods of recorded history in Eastern and Central Asia, whose people, although rich in poetry and culture, have remained stationary in technical knowledge for many centuries, ignoring pre-historic peoples and their monuments, and beginning our review with the nations bordering on the Mediterranean, we find there the birthplace of the engineer, the architect, the astronomer, and the mathematician. Nearly all the records of primitive times chronicle little else but deeds of heroism during everlasting wars between different tribes and nations, and it is to be presumed that the first employment for the engineer must have been with their armies, making roads and building crude fortifications. Mechanics and craftsmen of all kinds were very scarce, and it is no wonder, as Homer tells us, that the great Ulysses himself, the hero and chief of a nation, had to construct with his own hands the ships he sailed in, and had to design and execute in person the decorations of his palace. But as the savage spirit of perpetual war somewhat subsided, and as commerce increased, and as navigation began to be better understood, it soon became necessary to improve the natural shelter of harbors by artificial means; and to the Phœnicians, probably, belongs the credit of employing the first civil engineer to construct the celebrated and ancient harbors of Sidon and Tyre. This enterprising people, as long ago as 1280 years before our era, passed the Straits of Gibraltar in their ships, and founded the port of Cadiz, where they erected docks and large warehouses to accommodate the goods of the then known world.

Egypt, another country of the greatest antiquity, deserves, undoubtedly, the credit of being the cradle of all science, and of nursing it with the greatest care. Greece drew all her knowledge from there, and it must be admitted that a great amount of modern engineering skill had its origin on the banks of the Nile; 2,300 years B. C. a king of Egypt changed the course of the Nile from the foot of the sandy mountain on one side through the center of its valley, by constructing new and deep channels and several canals. By this simple method he reclaimed thousands of acres of marshes, raised the surrounding lowlands by filling with the material excavated, until it was above the annual inundations of the river, and thereby enabled his successor to build large cities with safety upon sites thus raised above the floods. Each successive monarch improved and continued the construction of canals and storage lakes, until the whole valley of the Nile became the most fertile and prosperous country on the face of the earth, and 4,000 years of misrule and fanaticism have been unable to this day to destroy the results achieved by the system of drainage and irrigation as founded by King Mines and his engineers. The construction of the pyramids, obelisks, sepulchres, and magnificent temples, especially those of Isis and Serapis, together with other innumerable monuments of antiquity, was per-

haps the joint effort of the engineer and architect, although it is most likely in those early times the two professions were not divided as they are to-day, and they are still depending more or less upon each other for success.

The inscriptions upon nearly all these proud remains of ancient skill show conclusively that the chisel, the mallet, and nearly all the tools as used in our present time for the quarrying and dressing of stone were known to the old Egyptians, and it is marvelous to contemplate how thoroughly the principles of the lever must have been understood by them, in order to move for many miles from the distant quarries, and raise to great heights, the enormous masses of stone used in their construction.

The great development and the high cultivation of the sciences and arts rapidly increased a taste for luxury and ease, and naturally destroyed the warlike spirit of the people of Egypt. They were in turn conquered and oppressed by the Greeks and the Romans, but the material progress founded by their engineers upon the laws of nature, then just dawning upon the brightest mines, could not be suppressed; the conquerors became the pupils of their slaves, and both the Greeks and the Romans carried their newly-acquired knowledge home with them, enlarged upon it, and used it with skill and energy, so that the then known world was rapidly changed. Wherever the conquering arms of the Romans were carried, through Gaul into Germany, and over to Britain, through Greece into Asia Minor, and India, to the very gates of Cathay, the engineer followed and often led the way. Without his assistance and skill it would have been impossible for the Romans, in spite of their disciplined courage and their great administrative ability, to keep together for so long a period the vast incongruous empire they founded. The magnificent highways constructed by their engineers, the artificially improved and well-defended harbors selected by them, the temporary but very effective defences thrown around their camps, the strong walls and deep moats they built around their outlying fortifications in distant provinces, and the enormous engines of war for defence and offence, invented and brought into practical use by their mechanics, enabled the consuls and emperors of Rome to move and concentrate their legions with great rapidity, and to hold far away settlements of importance for many months against the fierce attacks of barbarians, until assistance could be brought forward from the center of life and energy at Rome. Besides the constant activity of the military engineer, for Rome was rarely without a great war on its hands, the civil engineer was never idle during the many centuries of Rome's glory. The whole empire, as it existed during the reign of the Antonii, bore witness of the scientific knowledge, and genius, and energy of its engineers. Not only in Italy, but also in every conquered province from the Atlantic Ocean to the borders of India, from the Baltic Sea to the Sahara Desert, the engineer of that period has left great monuments to attest his skill and fertility of mind. The many miles of costly aqueducts scattered all over the empire, the innumerable public and private baths located in every city founded by the Romans, the immense amphitheaters, the magnificent temples and palaces, the handsome and numerous stone bridges, some of them unrivaled in their magnitude even in modern times, the great network of canals for the uses of irrigation and navigation, often cut through mountains without the use or knowledge of any explosives—all of these stupendous works constitute the imperishable evidence of the important part the engineer has always played in advancing material prosperity and civilization.

Of all the great engineers that must have existed during these ancient times, Archimedes, of Syracuse, was probably the greatest mechanic; he is at least one of the few men of that type of whom we know anything definite. Everyone is familiar with the wonderful defense of his native city, as conducted by himself by means of his mechanical engines of war, until he was slain at the age of 78 by a common soldier, during a successful assault of the Romans. He is, above all others, the one man who laid the foundation of scientific research, the prosecution and improvements of which are the boast of the present day; but especially celebrated is his treatise on the principles of hydrostatics, which he studied during his travels in Egypt, and

upon which are erected all the theories of hydro-dynamics and hydraulic architecture, as practiced by the engineers of Italy and France after the Renaissance.

During that long period of the Dark Ages, from the downfall of the Roman Empire to the beginning of the 17th century, the civil engineer can hardly be said to have existed; brutal ignorance and mental darkness took again possession of the earth, nations were again annihilating and exhausting each other by constant wars, and every tyrant and religious fanatic seemed to be bent upon destroying what his ancestors had created for the benefit of mankind. The sciences and arts were only partly preserved, and only practiced in secret, either by a few monks superior to their kindred, or by the Free Masons, the Brothers of the Bridge, and a few other secret societies.

To Rome belongs the glory of having accomplished, by her enterprise and knowledge, more than any other nation of antiquity for the development of the resources of our globe, and to Italy belongs the credit of reviving culture, the sciences and the arts, after the religious bigotry that kept men's minds in bonds had been challenged and attacked by the liberty-loving people of northern Europe. It may be said that the civil engineer reappeared about the middle of the 17th century, when it became necessary to drain the marshes and submerged lands of Italy. Many eminent writers on philosophy and mathematics arose about that time, and the sound theories they established gave a new and better light for practical work to the engineer and mechanic. Galileo and Descartes were the great teachers of that period, and made rapid advances in the true understanding of the forces of nature. Since the time of Archimedes, the theory of equilibrium had been understood and practiced, but Galileo taught and explained, and believed in his theories of motion, and Descartes made complicated problems and tedious calculations soluble and comparatively easy by the introduction of algebra. Ever afterwards and up to the present time, progress, especially in mechanical engineering, has been constant, and within the last hundred years enormous.

When in the beginning of the last century England furnished a Newton, and Germany a Leibnitz, to teach the true principles of dynamics and of pure mechanics, the minds of practical engineers were prepared and ready to utilize their knowledge, and apply it successfully to the steam engine, invented by James Watt.

It can hardly be said that the civil engineer was known in England and France until the beginning of the last century. The celebrated school of *Ponts et Chausees* was established in France about the year 1720, and from it have since graduated some of the greatest mathematicians of Europe, and many able and practical engineers. England, although she had produced a few engineers of eminence in the construction of canals, and harbors and lighthouses, never gave evidence of all the technical skill that lay dormant among her people of sailors, merchants and country squires, until the steam engine was introduced in some of her factories. But then her progress was rapid, and her increase of manufactories, mining industries and commerce, grew to such enormous dimensions within a hundred years that she not only outstripped in influence and power all the other nations of Europe, but made the magnitude of Rome in her proudest days seem insignificant when compared to the wealth, and learning and strength of the British Empire.

The power of steam, and its application to the manufacture of iron, and to the production of every article of luxury and necessity that enters into our daily wants, has produced a far reaching revolution, not only in trade and commerce, and in the intercourse among the nations, but it has radically changed the very thoughts of men, until there is a larger gulf between our modern life and that of ancient Greece and Rome than there was between those cultured nations and the wild and naked hordes of the Scythian desert.

When finally the immortal Fulton applied steam for the propulsion of vessels through the water; when Stevenson ran his first locomotive engine from Liverpool to Manchester; and when Morse applied electricity to the telegraph, the revolution in our mode of life appeared almost completed, and man's power over the forces of nature and its elements, so constantly working against him, seemed

well nigh absolute. The human mind would be overawed by the results of its own achievements were it not so constituted by the rapid increase of physical science and the accumulating inventions and discoveries of mechanical contrivances and natural laws, as to look upon every new improvement as a matter of course, until the telephone, and the electric light and the electric engine have have become no greater wonder to our children "than the cooking of a dumpling, although the question as to how the apples got into it has been a mystery to some minds."

It would require volumes to recite with anything like justice the enormous works executed by public and private enterprise within the memory of living men; it would take column after column to record the names of eminent mathematicians and engineers who enlarged the scope of scientific knowledge and carried it into practical execution, and it is impossible in an address so limited as this is meant to be to dwell upon these interesting matters.

Leaving, therefore, out of consideration the great wealth expended within less than a century by the nations bordering on the Northern Atlantic in sanitary, and mining and military engineering; on the improvement of harbors and the construction of steamships and docks; on the development of cheaper methods in the manufacture of iron and steel; on the erection of immense establishments for supplying water, and light, and clothing, and hundreds of other daily necessities that have put it within the reach of the poorest laborer to live in more bodily comfort than the well-to-do citizen of antiquity—putting aside these important enterprises and looking only upon one great achievement of modern engineering, the construction of railroads all over the known world, then it becomes at once apparent what immense progress we have made in technical knowledge, and what infinite benefits mankind has derived from it.

When the future historian, perhaps Macaulay's New Zealander, shall chronicle the history of our times, this generation will not become celebrated by the beauty and grandeur of its architectural remains, nor by the romance and sublimity of its epic poems; but on account of its knowledge of natural law, of its technical ability, of its practical skill in engineering, and on account of the comfort, the health, the freedom and the enjoyment that these acquirements have brought within the reach of the humblest of mankind.

The treasures spent by the ancients during long centuries of their supremacy upon temples and other monuments of architecture fade into utter insignificance when compared with the fabulous sums of money expended on the construction of railroads alone within the last fifty years.

Poor's Manual of Railroads for 1884, gives in his review of the year 1883, for the United States alone, a mileage of 110,414 miles of railroad completed and in operation. They were constructed at a total cost in round figures of $7,500,000,000, and the gross earnings of that one year amounted to $833,000,000 of money, a sum larger than the revenues of the British Empire and the United States put together. All this vast amount of wealth has been invested, not to satisfy the vanity of some great general or emperor, not to glorify some pagan deity, or to cater to the taste of a turbulent populace, but in order to consolidate a great and free nation, to make possible the daily intercourse of a people living thousands of miles apart, and to exchange freely and rapidly and without interruption the products of their labor.

Surely the engineer is entitled to the lion's share of the credit due in bringing about this unparalleled prosperity of the country. From his brains originated all the designs for the large and substantial bridges that carry our highways and railroads over the largest rivers, and thereby overcome the barriers nature had put there. The engineer conceived and located, and he supervised and directed the host of laborers, craftsmen and mechanics that constructed and equipped the many thousand miles of railroads that made the rapid development of this country possible. Daily millions of people trust their lives and fortunes to the care and skill of the engineer, to his ability and to his integrity—on the decks of steamboats, crossing oceans and lakes, and ascending and descending rivers; on railroad trains, crossing continents with uninterrupted

rapidity; in our palace hotels and in public halls, yes. in the very privacy of our houses, the whole community, from the lowest to the highest, is constantly at the mercy of the engineer, and any neglect on his part would at once be the cause of a great calamity, or of far-reaching annoyance and inconvenience. Yet with all this responsibility resting upon his shoulders, and often overburdened with care and worry brought about by the dangers of wind, and fire, and water, the elements that constantly threaten to destroy in a few moments what he had so carefully constructed during weeks and months of anxious labor, and after years of honest toil the engineer finds his reward generally in obscurity, and without financial success, with his health destroyed and nothing to console him save the proud consciousness of having done his work well and to his own satisfaction.

The name of many an able engineer is entirely unknown, until by some misfortune and accident, or perhaps by some oversight of his own, one of his structures fails and causes the loss of life and property; then he becomes at once a public character and gets to be notorious, but not famous, as he had fondly hoped to be. Every school-boy has on his finger-ends the names of kings and Cæsars, and orators of Rome, but who knows the name of the engineer that built the "Appian Way" or the "Aqua Claudia?" Everybody who can read a newspaper is familiar with the names of the emperors, generals and statesmen, and public agitators of England, and Germany and France, yet there are but few men, even in the profession, that can call by name, or know anything of the lives of the men who built the London and Liverpool docks, the first Thames tunnel, or the steamship Great Eastern; of the history of the engineers who built the Mt. Cenis or the St. Gothard tunnels? I am afraid able and scientific engineers in this country are not much better known, and are much more rapidly forgotten than many a disreputable politician. The construction of our Pacific railroads have ceased to be wonders; the East River Bridge, the most stupendous piece of work ever conceived and completed, is used by the public with the same indifference as a ferry boat, and the great explosion of the rocks at Hell Gate, a feat of engineering skill so colossal and frightful in its responsibility, was forgotten a few days after it was fired.

One would naturally suppose that the construction and management of railroads would bring the engineer prominently to the front, but such is not the case. "Financiers" and "business men," without any knowledge whatever for the position, except their judgment, good or bad, are put above him, and his technical training is often a drawback to his advancement.

It is true there are a few conspicuous examples of railroads in this country that are entirely controlled by engineers, and I need hardly dwell upon the good result obtained, and upon how much such management is to their credit. It is a well-known fact, not only to railroad men, but to all the traveling public, that the railroads so controlled are infinitely superior, especially in their physical condition and equipment, to those managed by men without technical training, be they ever so able and energetic otherwise. I would like to go into detail upon this subject, but the natural modesty so common in our profession bids me halt.

It is, however, a constant wonder why the great men of finance and those who by their investment control the management of railroads, and who have suffered so much during periodic railroad depression, will learn nothing from experience, and will not accept the evidence of successful management by men technically trained for that purpose.

I think that nearly every engineer, at least all those who have devoted their time, and energy and health to the business, will agree with me about the subordinate position held by them, when compared with the other professions generally called classical and learned.

If this is admitted, it becomes the duty of everybody to look for the cause and to go to work and find a remedy. Perhaps a great many engineers neglect business habits and confine themselves too much to technical questions; others, again, pay no attention to culture and general literature; and others still become unpracticable because they devote all their time to pure science

and mechanics, which should be left to the Professor. But I believe the majority are kept so constantly down to the ordinary drudgery in order to get their bread, frequently without butter, that they lose all interest in study and fall behind their more fortunate neighbors. I have no doubt some blame for all this is due to our Polytechnic schools; their training is too narrow and not far-reaching enough to enable its graduates to cope successfully with the ever increasing demand made upon the profession both in Culture and Technic.

There is one grand remedy for this evil that I would not only suggest but urge upon all, namely: unity of action, harmony among ourselves, and mutual support. The lawyers give us a shining example in that direction. I have come in contact during my career with many eminent men in that profession, and I have always noticed that although during disputes in open court or before a master they frequently are full of wrath against each other, and spare neither satire nor innuendo to get the best of their opponent, yet outside of the arena, in private or in public, I have yet to hear the first unkind word, derogatory to his ability, spoken by one attorney against another.

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# INLAND NAVIGATIONS IN EUROPE.

By Sir CHARLES A. HARTLEY, K.C.M.G., M. Inst. C. E.

A Lecture before the Institution of Civil Engineers.

## I.

The subject on which the Council has done me the honor to ask me to lecture this evening is so vast in its scope that I fear that in whatever way it may be treated, in the short space of time at the disposal of a lecturer, the result cannot fail to disappoint a portion, at least, of his audience.

With a view to minimize this natural feeling of disappointed expectation, I think it best to announce at once that my remarks to-night, instead of referring, as might naturally be expected, almost solely to inland navigation in connection with the United Kingdom, will direct your attention almost exclusively to certain important inland navigations and river improvements on the continent of Europe, with which, owing to my avocations abroad for a period of nearly thirty years, I am in a measure practically acquainted. In other words, I naturally prefer to confine my observations almost wholly, and with but one exception, to that part of the subject of my lecture on which I have some direct knowledge, namely, to systems of large river navigations in Europe—for time will not allow me to allude, even in the briefest way, to navigations in other quarters of the globe—rather than to dwell at length on the more popular subject of home navigations, concerning which the majority of my audience are doubtless already much better informed than myself, or, in any case, may speedily become so after reference to the many excellent publications on rivers and canals to be found in every public library, and especially on the well-stocked shelves of this Institution.

With regard to the actual cost of transport by inland waterways as compared to the cost by land, the question is evidently too large to be discussed with advantage on the present occasion. In what follows, therefore, I shall only touch incidentally on this important subject, and refer you for the latest and most authentic details thereon to the Report on Canals published in July, 1883, by order of the House of Commons.

The history of canals from the time of Alexander, the Ptolemies, and Marius, down to the days of Riquet, Brindley, Smeaton, Telford, Rennie, and De Lesseps, is published in countless volumes accessible to everyone. I need not, therefore, follow in the old track, and try to follow vary the recitals by conjectures concerning the priority of invention, by the Italians or Dutch in the fifteenth cen-

tury, of the lock, by which alone inland navigation eventually became generally applicable and useful; nor need I dwell on the fact that at home and abroad, during the latter half of the eighteenth century, there was as great a rage for canals as in the second quarter of this century for railroads.

I should not omit, however, to notice the circumstance that, great as has been the check by the introduction of railways to the construction of canals for the use of barges, the latter part of the present century will ever be famous for its great isthmian ship canal, such as the so-called artificial Bosphorus at Suez, which has already diverted the old lines of commerce in a remarkable manner, and the Panama Canal, which is apparently destined to effect a still more notable revolution in the old trade routes before the end, let us hope, of the present decade.

But as the theme allotted to me is inland navigation, I must perforce be silent on the topic of inter-oceanic water-ways; and the same restriction applies to tidal ports and tidal rivers—a subject which is in the programme of a lecture to be delivered next month from this platform by a very distinguished member of this Institution, Mr. Thomas Stevenson, of Edinburgh.

As to the theoretical part of my subject, I have no new theories to propound, or old ones dressed up in a new garb, to place before you; but in saying this, I desire to indicate to any student in hydraulics who may be present to-night the best sources of information with which I am acquainted concerning the most generally accepted theories in this country, and the most recent experiments of value on the flow of water, namely, Dr. Robison's remarkable article under the head of "Rivers" in the last completed edition of the "Encyclopædia Britannica," and to the experiments of Major Cunningham, R.E., on the Ganges Canal.

### INLAND NAVIGATION IN GREAT BRITAIN AND IRELAND.

The lower parts of the chief rivers of the United Kingdom are mostly arms of the sea, navigable at high water by ships of the largest burden. Higher up stream, where the tidal influence is gradually dimininished, they are generally navigable for ordinary river steamers, and, finally when the tide is no longer of any avail, they are in many cases canalized for the use of barges up to points which appear to be best adapted for the departure of entirely new water-ways to navigable channels in other river basins.

As a case in point, the Thames (218 miles in length) is navigable for the largest vessels from the Nore to London Bridge (48 miles), and thence for ordinary steamers to Teddington (20 miles), where the canalized portion of the river begins, and whence it is navigable as far as Lechlade, situated at 24 miles below Thames head. The total fall between the latter and London Bridge (170 miles) is 250 feet. Again, the Thames, at certain parts of its course above London Bridge, is united by means of a grand network of canals with the Solent, the Severn, the Mersey, the Humber, and the Trent; and thus, independently of its estuary, the Thames is in direct inland communication, not only with the English and Irish Channels and the North Sea, but with every inland town of importance south of the Tees. With reference to the estuary of the Thames, trustworthy evidence was taken before arbitrators in 1879–80, in a case concerning the navigable condition of the Thames, by which it appeared (1) that of the entire area of its basin, 5,162 square miles, 3,676 belonged to the non-tidal area, and 1,486 to the tidal portion below Teddington; (2) that the mean volume discharged from the tideless portion was 1,540 cubic feet per second over a period of twenty-five years ending 1878, or about 2,000 cubic feet per second at Crossness, 13 miles below London Bridge, from a total area of 4,661 square miles; and (3) that at Crossness the proportion of inland water (when the river is running moderately full) to tidal water (at an ordinary spring tide) is 1 in 26.

These figures are given with a view to enable comparisons to be made between our famous English river, on which is situated the chief commercial port and city in the world, and certain rivers on the Continent, shortly to come under review, of incomparably greater magnitude, but nevertheless of infinitely less importance as great highways of trade.

The absolute length of inland navigations in the British Isles seems to be rather a difficult matter to arrive at with

exactitude, for whilst Mr. Calcraft of the Board of Trade states it to be 2,688 miles in England and Wales, 256 in Ireland, and 85 in Scotland, or 3,020 miles in all, exclusive of the rivers Thames, Severn, Wye, Humber, Wear, and Tyne in England, the Shannon and other navigations in Ireland, and the Clyde, Forth, and Tay in Scotland, Mr. Conder, M. Inst. C.E., who has for many years past given special attention to railway construction and the cost of transport generally, estimates the length of inland waterways at 4,332 miles in England and Wales (of which 2,919 are canals and canalized rivers, and 1,413 navigable rivers), 755 in Ireland, and 354 in Scotland, or a total 5,442 miles. As to the cost of construction, the same authority has obligingly informed me that according to his researches the total cost of the canals and canalized rivers in England and Wales (4,332 miles) was £19,145,866, giving an average of £6,052 per mile, the minimum (Fen water canals, 431 miles) costing £4,000 per mile, and the maximum (Thames and Humber river and canal systems, 393 miles) £10,000 per mile, including the Regent's canal, which cost £120,000 per mile.* The carrying power of barges on British canals varies, with but few exceptions, from 20 to 80 tons when loaded down to draughts of from 3½ to 5 feet. The average dimensions of the locks, by which of course the size of the barges is regulated, are 80 feet by 14 feet, not taking into account of course the exceptional cases of the Weaver navigation (the best study in England at present of modern canal appliances), the new Aire and Calder canal, and the Gloucester and Berkley canal. There is a lock on English canals at every 1⅓ mile on an average, and the loss of time they occasion to barges is estimated at about two minutes per mile. Taking this retardation into account, the mean speed of barges in England by horse traction may be stated at 2½ miles per hour.

According to Mr. Conder, the working expenses of steam lighters on the Forth and Clyde Canal (35 miles long, and accommodating vessels of 8½ feet draught) are 0.23d. per ton per mile, including all expenses, but excluding interest on works; the average working expenses on all the English waterways are 0.26d. per ton per mile, or 0.37d. including 4¼ per per cent. interest on capital, and the cost on the Thames 0.10d., as compared with 0.083d. per ton per mile on the Aire and Calder Canal, for steam-tug expenses only.

There are no examples in the United Kingdom of cable-towing. A costly experiment of the system was tried on the Bridgewater navigation some years ago, but it was not adopted there, as the distances between the locks are short and the navigation tortuous.

No account, however short, of British waterways should omit to mention Telford's masterpiece, the Caledonian Canal. This celebrated work has a length of 60½ miles, of which 37½ are natural lake navigation, and 23 are artificial or canal navigation. The standard depth of the canal is 18 feet, giving access to vessels 160 feet in length, 38 feet beam, and 17 feet draught. The summit level is 102 feet above the sea, and at Corpach, its southern extremity, eight locks are clustered together up the side of a hill, to overcome a height of 64 feet. The cost of the canal was about £1,000,000 sterling.

### INLAND NAVIGATIONS OF THE CONTINENT OF EUROPE.

It is a far cry from England to Russia, but as this lecture is meant to embrace inland navigations generally throughout Europe, a succession of long and sudden leaps is unavoidable in a voyage covering so much ground. Hence my excuse for hurrying on without further preamble to the most northerly country of the Continent, with the intention of then working west about to Roumania, which marches with her gigantic neighbor along mid-channel of the lower Pruth to its mouth near Reni, and thence by the left bank of the Danube and the new frontier line of the Kilia mouths to the Black Sea.

### RUSSIA IN EUROPE.

European Russia is forty times larger than England, having in round numbers a length of 1,600 miles from the confines of Scandinavia, Germany and Austria, a width of 1,300 miles from the Arctic Ocean to the Black Sea, and a total area

* The total length of railways open for traffic in the United Kingdom on the 1st January, 1884, was 18,681 miles, and the total capital paid up thereon £784,921,000, giving an average of £42,000 per mile.

of 2,000,000 square miles, or more than one-half that of Europe.

With the exception of the little group of the Valdai Hills the main divisions of European Russia are the frozen "tundras" of the Arctic coast, the rock and Lake Plateau of Finland, the great forest and corn-bearing land of the central region, and the vast treeless "steppes" or pastoral land of the south and south-west, the chief characteristic of the whole landscape being that of an apparently illimitable gently-rolling plane, without a hill in view to break the monotony of the horizon. Thanks, however, to its comparatively low elevation this enormous region enjoys a river and lake system of navigation on an immense scale, and in order to complete Nature's handiwork—for hitherto Russian rivers have been little improved by the hand of man—a well-considered system of artificial canals has been established, by means of which the whole country can readily be traversed by water from end to end. European Russia possesses 19,000 miles of navigable waterway, and 38,000 miles of raft-bearing rivers. In summer these great highways transport raw products to the south and west, and receive back manufactured goods, whilst in the long winter months, from October to May in the north, and from November to April in the south, all inland traffic is necessarily carried on either by means of railways, of which there is already a length of 16,000 miles in European Russia, or by sledges over the frozen ground in districts where railways are still unmade or temporarily buried in snow.

The chief inland water-ways of European Russia will now be briefly passed in review, after drawing attention to the fact that the great watershed of Europe, that which separates its northern from its southern drainage—coincides throughout the eastern half of the continent with a low range of hills, which, in their greatest elevation, the Valdai plateau, hardly reach more than 1,100 feet, and which widens out in some parts into an expanse of marsh.

Thus, to the north of this watershed the Petchora flows into the Arctic Ocean, and the Dwina into the White Sea, to the north-west the Neva and the Duna fall into the Baltic, to the south-east the Ural and Volga fall into the Caspian Sea, and to the south, the Don, the Dnieper, the Bug and Dniester fall into the Black Sea.

The Petchora, 915 miles in length,* with a drainage area of 127,000 miles, has but 10 feet of water on its bar, and is only free from ice during a third of the year. Nevertheless its traffic in cereals and raw produce in the short summer season is very considerable.

The Dwina has a course of 650 miles, and becomes navigable on receiving the Vichegda, where it turns to the north; but though at the port of Archangel the water is very deep it is only accessible to vessels of less draught than 14 feet—maximum depth over the deepest of the four mouths of the river which empty themselves into the gulf of the Dwina, about 30 miles below Archangel.

The Ural has a course of 1,446 miles, and drains an area of 95,000 square miles, but the volume of its waters does not correspond with its length and the extent of its basin as compared with rivers in moister climates. It is navigable for small craft for most of its length, and enters the Caspian by three mouths of great width but insignificant depth.

The Volga, the longest river in Europe, and the chief commercial road of the whole Russian Empire, rises in the Valdai Hills, at an elevation of 663 feet above the Caspian Sea, into which it flows through upwards of seventy mouths, after a tortuous course of more than 2,000 miles. Its drainage area is 563,000 square miles. With its tributaries, it affords 7,200 miles of navigation, and is connected by canals with the White and Black Seas, the Baltic and the Azov. The Volga first becomes navigable for small steamers at Tver, whence it flows almost due east to its confluence with the River Oka (which drains 93,000 square miles) at Nijni Novgorod, so celebrated for its great fairs, and then on in the same direction to the large manufacturing and semi-Asiatic town of Kazan. Hence to the Caspian Sea, there are said to be only four towns on the left bank of the river, as against more than thirty on the right; and this is readily accounted for by the fact that it is chiefly the left bank that is

* The areas of the drainage basins of Russia and Germany are mostly after Strelbitsky. All measurements are in English statute miles of 5,280 feet.

liable to be flooded, the right bank being mostly the higher and steeper of the two —a remark, it may be said in passing, that also applies to the Dnieper, the Don, and the lower Danube. About 50 miles below Kazan and 300 below Nijni Novgorod, the Volga receives the waters of its chief feeder, the river Kama, which rises in the Ural mountains, and drains 200,000 square miles. As upwards of 900 miles of its total length of 980 are navigable, and as it is the great artery of communication with Siberia, the traffic of the Kama is very important. From its confluence with the Volga to Astrakhan, the great river flows nearly south for 1,200 miles, and, owing to the dryness of the climate, receives no other tributary of importance in the remainder of its course to the sea. In this distance it spreads out in many places to a width of several thousand feet, with depths varying from 3 feet at dry seasons, where the width is abnormal, to 50 feet and upwards in the concavities of sharp bends and in narrow places.

Hitherto no permanent works have been undertaken to improve the navigation of the Volga, and the Russian Government will hesitate a long time yet, I think, before rushing into heavy works for that purpose, for not only would they be exceedingly costly, but their effect would be very uncertain. Meanwhile, in the lower part of the river, the removal of shoals which are formed annually by the spring floods is effected by dredging, by provisional lattice groynes, and, during the last three or four years, by what is called a new system of iron harrows, which are said to have doubled the navigable depth over certain shoals in a few days, and, in one instance, at the Chebocksarsk shoal, where the depth was only 2 feet 4 inches right across the river, to have deepened the water 3 feet in six days, over a sufficiently wide channel, and to have given a depth therein of two meters in a fortnight. This reference to shallow water in the Volga will give an idea of the difficulties the navigation has to contend with at certain seasons of the year; nevertheless, upwards of six hundred steamers navigate the river and its chief tributaries, and trade goes on increasing rapidly.

Six days are generally needed to steam down from Nijni Novgorod to Astrakhan. Stoppages, both up and down stream, are always made at Tsaritzyn, on the right bank, which is connected by rail with Kalatch, on the left bank of the Don. The distance between the Volga and the Don at Tsaritzyn is only 49 miles, but as yet the only water communication between these two great streams is by means of the Upa canal, which connects the Oka with one of the upper reaches of the Don, thus uniting the Caspian Sea with the Azov.

The flourishing town of Astrakhan is situated on the right bank of the Volga, at a few miles above the head of the delta, 1,440 miles below Nijni Novgorod, 320 below Tsaritzyn, and 50 from the Caspian Sea. Although the Volga is longer than the Danube, and the area of its catchment basin 90 per cent greater, the volume discharged by the Volga is less than two-thirds of that discharged by the Danube, a circumstance which is explained by the fact that in the region traversed by the former there is relatively a much smaller rainfall than in the westernmost parts of Europe.

At the numerous mouths of the Volga, which frequently change in direction and volume, the south, or principal one, is happily kept open for the passage of small steamers by the action of the prevailing S.S.W. winds, which tend to drive the detritus northward, and thus partly to choke up the subsidiary channels to the north-east.

This inland sea has an area of 160,000 square miles, and the level of its surface is 84 feet below that of the Black Sea. Its trade is now very important, owing principally to the great increase of late years in the production of petroleum from wells sunk near that ancient seat of fire-worship, the Port of Baku. In 1883 the transport by rail and steamer of this industry alone amounted to 206,000 tons, of which more than one-half was produced by the enterprising Swedish firm of Nobel Brothers. A large fleet of cistern steamers are already employed in connection with this trade, and it will be interesting to engineers to watch the effect on the water traffic when the means now in progress to facilitate the land transport by rail and lines of iron tubing have been perfected. By this combined system of carriage it is anticipated that ultimately there will be no

difficulty in exporting the 250,000,000 gallons a year which experts assert can regularly be obtained from the Caucasian regions, a supply, it may be added, which is equal to the present wants of the whole world. Apropos of this interesting question of the petroleum trade it may not be out of place to quote a passage from a letter I received last month from H.B.M.'s Vice Consul at Odessa. He says: "We have in port a small, light-draught screw steamer—150 tons burden, dead weight—called the Samuel Owen, which has just arrived from Baku (Caspian Sea) *via* the Volga, the Marie system of canals, Lake Oneiga, River Neva, and thence around Europe to Odessa." Now, as the distance by land in a straight line from Baku to Odessa is less than 1,000 miles, and as the distance steamed over by the Samuel Owen must have been fully 8,000 miles, it appears to me that the voyage of this vessel is a remarkable illustration of the preference that is given, in certain cases, to water over land transport, even when the former mode of transport involves the delay attending an extraordinarily circuitous navigation by lakes, rivers, canals and narrow seas, to attain the end in view.

The Don rises in the Ivan lake, 586 ft. above the sea; its length is 980 miles, and its drainage area 170,000 square miles. This river is navigable for large rafts of timber down to the mouth of its first great tributary, the Toronjo, at Tavrovsky, on the left bank (where Peter the Great built his ships of war for the Black Sea), and thence to Kalatch it is navigated by small steamers. From Kalatch, which, as we have seen, approaches within 49 miles of the Volga, large freight steamers start several times a week for Rostov, the largest commercial town in Russia after Odessa, and situated on the right bank of the river at the head of the delta. The quantity of merchandise floated down, including the traffic of the Donetz, which enters the Don between Kalatch and Rostov, as well as that of the Sosna, another tributary which enters it between Voronej and Kalatch, is above 200,000 tons annually, exclusive of large deliveries of antracite coal, which is obtained from Novo Tcherkash and Lugan (about 100 miles below Rostov), and sent down the Don for the use of the Russian steamers in the Azov.

A short distance below Rostov, where, according to my own observations, the sectional area of the river at low water is 23,300 square feet, the Don splits up into two channels, which ultimately give birth to five separate mouths, at the deepest of which, the Perevoloka mouth, 25 miles below Rostov, and 15 miles from the Taganrog roadstead, the available depth is rarely more than 6 feet. During the summer of 1882, and in November, 1884, however, all the bars of the Don were completely dry for several hours, owing to the effect produced by a long-continued east wind. On the other hand, in 1866 (when the mouth of the river were surveyed under my direction), a long series of hydrographic observations recorded the interesting fact that after a long and stiff blow from the W.S.W., and therefore from seaward, the water at the Perevoloka mouth rose 9 feet above its ordinary level, thus giving a momentary depth of 15 feet on the bar, and so causing the current to flow upstream past Rostov with considerable velocity.

After this description of the mouths of the Don, it need not be said that the river is only accessible to coasters of light draught. Sea-going vessels either take in their cargoes from lighters in the straits of Kertch, where there is now a depth of 15 feet, or in the roadstead of Taganrog, which, on account of shallow water, is 10 miles distant from the port of Taganrog. Taganrog is one of the three privileged ports of the empire for the importation of foreign goods, and the great entrepôt for the commerce of the Volga and the Don.

The Dneiper drains an area of 204,000 square miles, and rises not far from the source of the Volga. In its length of 1,060 miles it flows nearly south from Smolensk to Kiev, below which its direction south-east to Ekaterinoslav, and thence south and south-west to the Black Sea. Its first great tributary below Smolensk is the River Berezina (which is joined to a branch of the river Duna by the Berezina Canal); but its most important feeder is the Pripet, which joins the Dneiper at about 60 miles above the city of Kiev, the "Jerusalem" of Russia. The Pripet is 380 miles in length, and rises within a few miles of the right bank of the northern Bug, which flows into the

Vistula. By the Oginsky Canal the Pripet is connected with a branch of the river Niemen, and thus there is an alternative means of inland water communication between the Black Sea and the Baltic. The Desna, the third tributary of importance, joins the Dneiper on its left bank at Kiev, and contributes a large quota of trade to the main river in the early summer, when it is navigable as far as Briansk in the province of Orel. At Kiev, where, as we all know, the Dneiper is spanned by Vignoles' magnificent suspension bridge, the river is 1,500 feet wide, but thence to Krementchug, about 100 miles above Ekaterinoslav, it occasionally exceeds 1 mile in width. The minimum depth between Kiev and Ekaterinoslav is 3 feet. At Krementchug a large trade is carried on in tallow, salt, grain, and beet-root sugar, and large storehouses are provided for the half-manufactured produce brought down the Dneiper and its tributaries from the provinces through which they flow, as well as for goods brought overland from the interior.

Steamers ply daily in summer between Kiev and Krementchug, and every other day between the latter and Ekaterinoslav, an important town on the right bank, about 60 miles above Alexandrovsk, a large port on the left bank, at the foot of the cataracts of the Dneiper. This great obstruction to the navigation, which I inspected in 1873 at the request of the Russian Black Sea Steam Navigation Company, is caused by a granite outshoot of the Carpathians, and consists of nine distinct rapids in a length of 47 miles, the total fall being 107 feet. The most formidable of these obstacles are the Kiodatsky, Nenasitetsky, the insatiable, and Volingsky Rapids, their average length being only 7,700 feet, with a total fall of 34 feet. Several abortive attempts were made between 1788 and 1883 to improve the navigation by means of side-cuttings near the shoreline, but no improvement of any kind was effected till 1853, when, after ten years' work, a series of canals were formed in the bed of the river, and protected at the sides by parallel walls of rock-work, furnished with splayed guiding-walls facing up-stream, with the view of allowing vessels of small draught to make use of them at certain seasons of the year, when the rapids would otherwise be impassable. In practice, however, their only use has been to allow of the occasional passage of undecked flat-bottomed barges carrying from 5 to 7 tons, and drawing 18 inches at extreme low water. At all other seasons the confined artificial channels, which have a width of about 140 feet, are regarded as mere traps at each one of the rapids, and are therefore always carefully avoided by descending vessels. No cargo-boats ever ascend the rapids, and the whole trade over them is consequently limited to rafts of timber and to raw and also manufactured produce floated downstream from long distances in lightly-constructed barges, which are broken up and the wood used for building purposes on their arrival at Kherson, a languishing port on the right bank at the head of the Delta, 216 miles below Alexandrovsk.

Immediately after passing Kherson, the Dnieper divides into several channels, and finally delivers its waters into the Bay of Kherson by nine mouths, at the deepest of which, by the aid of occasional dredging, a depth of 10 feet is generally maintained.

In spring, when barges drawing from 5 to 6 feet can descend the river from the foot of the rapids to Kherson, there are barges carrying 100,000 tons plying between Alexandrovsk and Odessa, a distance of 306 miles, at an average freight of 7s. per ton. At the low-water season, however, the rates sometimes rise to 15s. per ton.

The Southern Bug rises in Podolia, and after a course of 430 miles enters the Bay of Kherson at 30 miles west of the town of Kherson. It drains 26,000 square miles, and can be navigated by craft drawing 6 feet for about 80 miles above the town of Nicolaev, which stands on the east bank of the river at 20 miles from its mouth, and at the junction of the rivers Ingul and Bug. Nicolaev is the Russian arsenal of the Black Sea, and ships-of-war are built and launched here, and pass into the Bug from the Ingul by a channel 20 feet deep, a depth which diminishes to 17 feet at the entrance of Kherson Bay, off Kinburn. The tonnage of vessels cleared from the port of Nicolaev with cargoes of grain in 1882 was 162,000, a shipment which is much below the general average.

The Dniester rises in the Carpathian Mountains in Galicia, and flows south-east into Russia. It forms the boundary between Bessarabia on the right, and Podolia and Kherson on the left, and its waters, after passing through a wide and shallow estuary below Akerman, enter the Black Sea on a low sandy shore between Odessa and the Danube mouths. Its total length is 640 miles, and, like the Bug, having no tributaries of importance, it only drains 30,000 square miles. Its channel is broken up by rapids near Bender, and below that historic town is only navigable for vessels drawing less than 8 feet, whilst at its principal mouths the depth varies from 4 to 6 feet.

A long leap backwards must now be made to the north of Russia, to carry out my programme to work west about from the North Sea to the Danube mouths.

The Baltic has been well termed an estuary rather than a sea, receiving as it does a number of rivers, none of them individually of great size, but collectively draining an area equal to one-fifth of the entire area of Europe. Near the mouths of these rivers, the depth of water becomes greatly diminished, and, like the Black and Caspian Seas, there being little or no tide, and the water being comparatively fresh, the surface of the Baltic, which is emphatically a shallow sea, soon becomes frozen. Hence all its ports are sealed up for more than a third of the year, and during this long period the inland navigation of north-eastern Europe is entirely suspended.

The Neva is only 34 miles long, and its waters are immediately derived from Lake Ladoga, which, having a surface of 7,000 square miles, is the largest fresh-water lake in Europe. The Ladoga receives the contributions of numerous other lakes, including Lake Onega, which covers area of 3,800 miles, or seventeen times that of the Lake of Geneva. The entire area drained by the Neva is 112,000 square miles, and through Lade Onega it is connected with the Dwina and the Volga by canals, through which small vessels can pass from the Baltic into either the White Sea or the Caspian.

Before taking leave of the Neva, a few words should be said regarding the new canal, which now unites the commercial harbor of St. Petersburgh and the military port of Cronstadt. When I journeyed between these two places on the ice in mid-channel in the upper part of the Gulf of Finland, in 1869, the carrying trade through the Baltic, to and from St. Petersburgh, had to be done almost entirely by transhipment at Cronstadt, as at that time lighters only could cross the 8 to 9 feet of water at the long bar of the Neva. The construction of a maritime canal to unite St. Petersburgh and Cronstadt, designed originally by Peter the Great in 1725, was only begun in 1878, and thrown open to commerce in October last. This canal is 18 miles in length, with a floor width of 276 feet, and an actual depth of 20 feet. This depth is now being increased to 22 feet at ordinary low water. With regard to this level, it is worthy of notice that, during the construction of the works, strong winds from seaward raised the level of the gulf 9 feet on one occasion, whilst on another a strong N. E. wind lowered the water 5 feet; the extreme difference being 14 feet, as compared with 15 feet from the same causes at the mouths of the Don.

The estimated cost of the St. Petersburgh Canal is 10,000,000 roubles, a sum well spent, in my opinion, on such a work, although, notwithstanding its obvious utility, both from a commercial and strategical point of view, there are many self-dubbed authorities, especially among those interested in the lightering trade, who maintain, as invariably happens in similar cases, that the canalization will turn out anything but a success in practice.

The Duna rises near the source of the Volga, and drains an area of 33,000 square miles. Its length is 470 miles, and its general direction north-west. It forms the frontier between Livonia and Courland, and enters the Gulf of Riga 7 miles below the town of Riga. The navigation of the river is obstructed by rocks and sandbanks, but during the floods of spring and autumn its products are readily transported in barges to the Baltic. The depth of the navigable channel at Riga is 17 feet, but at the entrance to the Duna, at the head of the north pier, 9 miles below Riga, the depth in 1881 was only 14 feet.

The total length of the canals in

European Russia is about 900 miles. In most instances they have been formed with but little difficulty across the gentle undulations of the great watershed, thus uniting, as we have seen, the head-waters of rivers which have their outlets at opposite extremities of the continent.

SWEDEN.

Sweden abounds in lakes, which cover more than 14,000 square miles of its surface. Of these the Wenern and the Wettern are the largest, the former having an area of 2,400 square miles, and the latter 760. The Mälar Lake, with its one thousand three hundred beautiful islands of all sizes, is also of great extent. None of the rivers are navigable, excepting those which have been made so artificially, and nearly all are obstructed by cataracts and rapids. Nevertheless Sweden has remarkable facilities for internal navigation, during the seven months that the country is free from ice, by means of a series of lakes, rivers, and bays, connected by more than 300 miles of canals. These furnish direct water communication between the Baltic and Gothenburg, the chief commercial town of Sweden, situated upon the estuary of the Gotha river, 5 miles from the Cattegat. Plans for effecting this communication were devised long before they were carried out. In 1800 the Trollhattan or Gotha canal, at the head of the river Gotha, where it descends 108 feet in 5 miles, was opened to the navigation, and improved and widened to the dimensions of the Gotha canal between 1836 and 1844. This celebrated canal, which I visited in 1880, was founded in the beginning of this century by Count Von Platen, the De Lesseps of his day. In 1808, he summoned to his aid Mr. Telford, the first President of this Institution, who, after visiting the ground, prepared and sent in a series of detailed plans and sections, with an elaborate report on the subject. His plans were accepted, and the works were begun in the following year, but although the West Gotha canal was opened for traffic in 1822, the two Swedish seas were not connected before 1832. Of the entire distance of 370 miles between Stockholm and Gothenburg, only about 50 are canal, and the same distance along the coast of the Baltic, the remaining 270 being through lakes, bays and rivers. The canal is now everywhere 48 feet wide at the bottom, 90 at the surface, and 10 feet deep. In 1855 it was thrown open to steamers. Its most elevated point is Lake Wiken, between Wettern and Wenern, where it is 300 feet above the level of the sea. The descent is made by vessels through thirty-seven locks, or seventy-four from sea to sea; and as several of the lock chambers, which are 120 feet long and 24 broad, are grouped together where the ground is steep, vessels have the appearance every here and there of slowly descending a flight of gigantic stairs.

The total length of the railways in Sweden and Norway is 3,637 miles, of which one-third belongs to the State.

GERMANY.

The German empire owns parts of seven river valleys, and three large coast streams. Of the latter, the Pregel flows to the Baltic, and the Eider and Ems to the North Sea; of the former, the Niemen (or Memel in German), Vistula and Oder, flow to the Baltic; the Elbe, Weser and Rhine, to the North, and the Danube to the Black Sea. Of these seven large rivers, the Weser is the only one which belongs entirely to the German empire; of the Elbe and Oder the larger part; of the Rhine the larger half; but of the Danube only one-fifth part. The hydrography of all these rivers, with the exception of the Danube, will now be briefly described.

The drainage area of the Niemen (35,000 square miles) is conterminous with that of the Duna, and of about the same extent. The Niemen rises in Russia, becomes navigable at Grodno, and divides at Winge into the Russ and the Gilge, both of which fall into the Kurisches-Haff, one of those peculiar lagoons characteristic of the shores of the Baltic opposite their river mouths. The Niemen enters the sea at the port of Memel, the central point of the timber trade of the Baltic. The depth of its harbor is 23 feet; but on the bar of the river, 2 miles below the town, the depth is 18 feet only. By means of an artificial canal between the Upper Niemen and the Pripet, already described, vessels can pass from Memel to the Black Sea.

The Vistula rises in Austrian Silesia, in the Carpathian Mountains, at 2,000 feet above the level of the sea, and its basin drains 74,000 square miles, including Russian and Prussian Poland. In its length of 600 miles, it flows past Kracow and Warsaw, becomes navigable for vessels of from 7 feet to 8 feet draught at ordinary high-water level at the German frontier and carries this depth to its principal mouth at Plonsdorf, about 5 miles east of Dantzig, the chief port of Germany in the Baltic.

Dantzig is situated on the west, or left bank of an old arm of the Vistula, through which the current ceased to flow on the 31st of January, 1840, when, owing to the effect of a sudden break up of the ice, the river formed for itself a new mouth at Frondorf, nine miles below the old mouth at Neufahrwasser, which is now completely closed. In the following year a lock, with 10 feet of water on its sill, was built across the old arm close to the new entrance, to ensure the easy passage of river craft between Dantzig and the interior of the country, and in 1846 the old lock at Neufahrwasser, constructed in 1001–1805, being no longer needed, was destroyed, and a wide open channel substituted in its place.

From Dantzig to Neufahrwasser, a distance of 5 miles, and thence to deep water at the head of the east pier, the dredging of a channel 200 feet wide and 23 feet deep is now on the eve of completion.

In 1848 the navigation of the Vistula between the new mouth and the head of the delta, where the river bifurcates into the Nogat, or east arm of the river, and the Dantzig, or west arm, became so difficult that works of correction were begun in that year by the Prussian Government to ensure a regular flow of water through both branches, and, as it was hoped, to improve their navigable condition as well. In 1858, a short time after the works were completed, I visited the ground and obtained through the kindness of the Government engineers, certain technical information of interest, which I venture to reproduce in this place, as it refers to a very delicate operation in river engineering, namely, that of radically changing with success the relative flow of two branches of a great river at a point where they separate from their parent stem never to reunite. In the Vistula, immediately above the head of the delta, the volume discharged at zero or extreme low water is estimated at 8,766 cubic feet per second, and at high water, when its level stands at 10½ feet above zero, at 76,700 cubic feet per second. Of this quantity, three hundred years ago, two-thirds passed by the Dantzig branch, and one-third by the Nogat. The latter, however, having a steeper slope than its sister branch, went on gradually increasing in volume, until, in 1840, the proportions were completely reversed, and it appeared highly probable that unless the art of the engineer stepped in before long to re-establish the old order of things and to fix the flow at the bifurcation, the Dantzig branch would silt up altogether. Hence the contemplated works had principally in view the restoration of the old *regime*, by means of which the Nogat, instead of withdrawing two-thirds of the total volume of the main river, should have its flow permanently brought back to the original proportion of one-third only.

The works were admirably executed, and principally consisted of the cutting of an entirely new channel, furnished with incorrodible sills and revetments for the waters of the Nogat; the blocking up of its old channel by several substantial dams; the construction of extensive training works from the fork down to Dirchau on the one branch, and Marienburg on the other; and the construction of twenty-six massive ice-breakers across the new Nogat entrance.

The result of the works (the cost of which is estimated at £600,000) has proved:—1st. That the discharge of the Nogat as compared with that of the undivided Vistula, is only 10 per cent. at low water, 24 per cent. at ordinary water-level, and 28 per cent. at high water, and consequently the discharge of the Dantzig branch 90 per cent., 76 per cent., and 72 per cent. respectively of the total flow at the same periods. 2d. That a good navigable channel everywhere 8 feet deep is now available in the Dantzig branch, whilst at low water in the sadly impoverished Nogat the channel is impassable for vessels drawing more than 3 feet. 3d. That the ice-breakers have produced the desired effect of diverting all the largest ice-floes to the sea by the Dantzig branch;

and 4th. That the general result has apparently been to improve one branch of the river at the expense of the other.

In connection with the mouths of the Vistula, it should be further observed that the Nogat discharges itself into the Frische Haff by several very shallow channels near Elbing, where a lateral artificial canal permits steamers of small draught to enter the Haff and then to steer direct either for the mouth of the river Pregel, or for the Port of Pillau on the Baltic. The entrance to this seaport has deepened itself 10 feet since the completion of its piers in 1846, and has now a depth of 24 feet; but from its harbor to the mouth of the Pregel, 19 miles, and thence for 4 miles further on, to the great corn-exporting port of Königsburg, the channels through the Haff and river only admit of the passage of vessels drawing less than 10 feet.

The Oder rises in Moravia at an elevation of 1,000 feet above the sea, enters Prussian Silesia, traverses the provinces of Brandenburg and Pomerania, and after a course of 550 miles, empties its waters through the Stettin Haff or estuary into the Baltic. Its basin has an area of 50,000 square miles. The result of the large expenditure which has been incurred with the view of improving the navigation of the Oder, has thus far proved satisfactory. Works have been going on for some years past, and are now nearly accomplished, with the view of securing a depth of $3\frac{1}{2}$ feet between Ratibor, near the frontier of Silesia and Schwedt, 400 miles lower down. The other works of importance which have lately been determined on in connection with this river, are: the extension upwards of the navigable channel from Ratibor to Oderberg; the construction of another Oder-Spree canal, leaving the Oder opposite the mouth of the Werthe; whilst a project for a ship-canal connecting the Oder and the Danube has been planned in detail, and its execution seriously entertained.

The estuary of the Oder may be said to begin at Stettin, from which to place Swinemünde, a distance of 50 miles, a channel has lately been dredged to a depth of 20 feet over a width varying from 250 feet to 400 feet, so that sea-going vessels of 19 feet draught can now trade with facility from the mouth of the Oder to Stettin without transhipment of cargo.

The Elbe rises in the north-east of Bohemia, and one of its sources is about 4,500 feet above the level of the sea. It drains an area of 55,000 square miles, and next to the Rhine is the most important of German rivers. It enters the North Sea near Cuxhaven, and like the Duna, Niemen, Vistula and Oder, its general flow is in a north-westerly direction. Its principal affluents are the Moldau and Eger, both of which enter the Elbe on its left bank above the Bohemian town of Aussig, not far from the German frontier. Notwithstanding the comparatively favorable state of the river at ordinary water-level, the condition of its bed in some places at extreme low water was so deplorable in 1870 that a technical commission, which was convoked at that time, recommended the execution of a project which had for its object the permanent acquisition of a channel of a minimum depth of 2 feet 10 inches from the Bohemian frontier downwards.

According to Mr. Ludwig Hagen, who has the supervision of all the Prussian streams, the minimum depths at ordinary water are now 5 feet from the Bohemian-Saxon frontier to the Saxon-Prussian frontier at Anhalt (163 miles), 5 to 6 feet from Anhalt to Havelburg (103 miles), and 6 to $6\frac{1}{2}$ feet from Havelburg to Hamburg (121 miles). The practice of towing vessels of from 30 to 450 tons burden by men and horses between Aussig and Hamburg, has been almost entirely abandoned. As early as 1866, chain-tugs were running on 200 miles of its course, and in 1874 this mode of traction had been so much increased that there were then twenty-eight tugs running regularly between Hamburg and Aussig. These tugs are 138 to 150 feet long, 24 feet wide, with 18 inches draught. On the Upper Elbe the average tow is from four to eight large barges, and taking the ice into consideration, there are about 300 towing days in a year. On this river it has been found, as elsewhere, that vessels of large tonnage pay best. Thus, to the Hamburg Magdeburg Navigation Company (which has perhaps had more experience in the *modus operandi* of steam-tugging in inland waters than any other corporation in the world) the cost of transporting a

cargo from Hamburg to Dresden, a distance of 350 miles, for barges of 150 tons, 300 tons, and 400 tons, is, respectively, 11s. 6d., 9s. 9½d., and 9s. 4d., per ton up stream, and 4s. 4½d., 3s. 2½d., and 2s. 9½d. per ton down stream. These figures are given on the authority of Mr. Bauer, and have been selected as a fair type of the present method of traction with its precise cost on one of the best conducted inland water routes on the continent.

The formation of an internal navigation to join the Elbe, the Oder and the Vistula, has been successfully accomplished partly by the aid of secondary rivers and partly by canals. The canal of Mulrose unites the Oder and the Spree; the latter being a navigable river falling into the Havel, which in its turn falls into the Elbe near Havelburg. But the navigation from the Oder to the Elbe being difficult by this route, another communication was made by the Finow canal and a chain of lakes stretching from the Oder at Oderburg to the Elbe near Magdeburg. The Elbe being in this way connected with the Oder by a comparatively easy navigation, the latter has been united to the Vistula, partly by the river Netze and partly by a canal joining that river to the Brahe, which falls into the Vistula near Bromberg. A vast inland navigation has thus been completed by which barges of 110 to 125 tons burden, and drawing 3 feet at ordinary low-water level, can pass freely through the whole extent of country from Hamburg to Dantzig.

Before quitting the Baltic, a few words should be said with reference to an existing water communication across Holstein, and of a maritime canal which is shortly to be cut between Kiel and the mouth of the Elbe. The Holstein canal, formerly belonging to Denmark, is of great importance, joining, as it does the Baltic with the river Eider, which falls into the North Sea. The Eider is navigable for vessels of 9 feet draught from Tonning, near its mouth, to Rendsburg, where it is joined by the canal which communicates with the Baltic at Holtenau, about three miles north of Kiel, the chief naval arsenal of Germany. The canal is 26 miles long, and the excavated portion is 52 ft. wide at the bottom, and 9½ feet deep. It was opened in 1885 at a cost of £500,000.

The projected ship canal is to run from the mouth of the Elbe near Glückstadt to a point near Kiel, and is to be of such dimensions as to pass the largest war vessels in the German navy from sea to sea. When completed, this important undertaking will be of the greatest benefit to large steamers trading to the Baltic ports, and will supersede the present circuitous voyage by Jutland and the Sound, if the dues imposed are not prohibitory to the passage of merchant vessels.

The Weser has a length of 355 miles, and drains 18,000 square miles. In its upper part it traverses a mountainous district, and only emerges on the plain at Münden, whence to Bremen the distance is 230 miles. The system of improvement of the lower part of the river commenced in 1823 with the intention of securing a depth throughout of 1½ foot at extreme low water. Up to this time, however, the depth already obtained ranges from 1½ foot to 3 feet, thanks to the construction of an extensive series of groynes and training walls, and of a separate canal to avoid a difficult obstruction above Hameln. The barges now in use below Munden vary from 80 to 260 tons burden, and the proportion of laden vessels bound down stream is as six to one bound up stream. Works are in progress to still further improve the navigation of the Weser and its tributaries, especially the Fulda, down to Bremen, the second commercial town of Germany, situated on the right bank of the river about 50 miles from the sea. The depth of water at Bremen is only 8 feet, but at its sea port Bremenhaven vessels drawing 22 feet can enter safely, and, as at Hamburg, Bremenhaven is free from ice nearly all the year round.

The Ems rises on the confines of Lippe Detmold. It flows in a northerly direction, through Westphalia and Hanover, and empties itself through the Dollart estuary into the North Sea, near the town of Emden. It has a length of 200 miles, and is navigable for vessels of 200 tons to a distance of 14 miles from its mouth, and for small vessels as far as the town of Rheine, 75 miles from the sea.

The Rhine rises in Switzerland at an elevation 7,240 feet above the sea, and its basin receives the drainage of 76,000 square miles. Its total length is 850 miles. It first becomes navigable for

rafts at Reichenau, but thence to Bâle, 820 feet above the sea, its navigation is difficult, and in many cases impossible, owing to the existence of numerous rapids and cataracts, of which that at Schaffhausen, 70 feet in height, is the most remarkable. At Bâle the river trends to the north, and flows in that direction over a long flat plain to Mayence (310 miles from the sea, and 240 feet above sea level), at the confluence of the Main. In this part of its course floods take place annually, but since 1840 this evil has been greatly remedied by the formation of a navigable channel varying from 3 to 30 feet in depth, with high embankments confining the stream to a width of 807 feet. At Mayence the river again turns west along the south slopes of the Taunus, and at Bingen, where the navigation has been improved by the removal of rocks which formerly impeded the course of the river, it once more turns north, entering a narrow defile which its quits at Bonn to wind westward over a portion of the great German plain to Emmerich, a frontier town a little above the head of the delta. How the Rhine then breaks up into Rhine and Waal, Rhine and Yessel, crooked Rhine and Lek, and finally reaches the sea through several mouths on the coast of Holland, can only be well understood by reference to a large map of the Netherlands.

Between Mayence and Emmerich the average summer width of the Rhine is 1,300 feet. and its mean navigable depth 8 feet. At certain places, at extreme low water, in dry seasons, the available depth is not more than 2 feet, in spite of the large sums of money which have been spent by the German States during more than half a century on regulation works of magnitude, comprising dredging and blasting operations, and the construction of those massive parallel draining dykes and groynes which are so noticeable to the eye of every traveler between Bonn and Bâle.

The principal tributaries of the Rhine on the right bank are the Neckar and the Main, the latter of which is navigable for barges over the last 200 miles of its course. The Moselle on the left bank rises in the Vosges, and becomes navigable at Pont-à-Mousson in France, but is almost useless for navigation on account of its very tortuous course and of its shallow bar where it joins the Rhine at Coblentz.

There is another tributary of the Rhine, however, of small volume, but formerly of great importance, which, on account of its celebrated coal measures, great industrial resources, and certain physical peculiarities, deserves especial notice in any sketch, however slight, of German waterways. I refer to the River Ruhr, which joins the Rhine on its right bank near Duisburg, between the river ports of Dusseldorf and Wesel. The Ruhr is the water-road from the Westphalian coal districts to the Rhine. Its drainage basin, including that of its tributaries, the Lenne, Ennepe and Volme, is 2,000 square miles. Its minimum discharge is 300 cubic feet per second, and its maximum 58,245 cubic feet per second, or two hundred times more than its minimum volume—a very abnormal relation indeed. The navigable length of the Ruhr is 46 miles and its average and minimum widths are 164 and 68 feet respectively. The river has eleven locks, 147 feet long and 18 feet 6 inches wide, and the barges traversing them draw 3 feet 6 inches, and carry 180 tons. During the period 1855–78, the navigation was interrupted either by ice or by floods, on an average from a maximum of one hundred and fourteen days to a minimum of twelve days. On this account, and on account of the low transit charges of the network of railways, the importance of the Ruhr has become almost *nil*. Thus in 1855 there passed through the Ruhr lock at Muhlheim 750,000 tons, and in 1878 only 46,800 tons. Projects for the improvement of the navigation of the Ruhr have been made, but are not likely to be carried out. If anything is done it will be solely with the view of diminishing the floods. This recent information concerning the Ruhr was obtained for me from official sources by my friend, Mr. Henry Gill, of Berlin, M. Inst. C. E.

In the first reach of the river above the delta of the Rhine, 12 miles below Emmerich, the width of the undivided river in summer is about 1,800 feet, and more than double that width in winter; the mean discharge being 89,000 cubic feet per second, and the maximum 341,000. At the apex of the delta ex-

tensive training works have been constructed to regulate the flow of the river after it leaves the German frontier, the object in view being so to distribute its volume, that in all states of flood, high as well as low, two-thirds thereof should be conveyed into the Waal, and one-third into the Lek or Lower Rhine. The navigable depth of the deltaic branches of the Rhine varies from 4 to 10 feet. An interesting account of the great works which have been constructed to regulate the flow of the various branches of the delta of the Rhine will be found in the Minutes of Proceedings Inst. C. E.

Steam towage is almost universal on the Rhine, and, as on some other rivers, a great difference of opinion exists as to the relative merits of paddle tugs, chain-tugs and wire-rope tugs. In 1873, a wire-rope tug company laid down the line from Bingen to Rotterdam and worked the upper section of 155 miles themselves, and in 1874, on the Neckar, five tugs were employed on a length of 56 miles. By means of canals the basin of the Rhine is connected with the basins of the Rhone and Saône, Scheldt, Meuse and Danube.

Although Germany possesses a length of nearly 17,000 miles of navigable rivers, or more than double the combined length of the navigable streams of France and the United Kingdom, it cannot be said to be rich in canals. In South Germany the Regnitz and Ludwig's canals, from the Main at Bamberg to the river Altmühl, an affluent of the Danube, were the only artificial waterways of importance until the annexation of Alsace-Lorraine. The North German Plain has several canals, the most important of which I have already referred to in describing some of the chief river systems of the Empire. In 1878 the total length of the seventy canals of Germany was only 1,250 miles, a very small extent when compared with the other canal systems of Western Europe.

### HOLLAND.

Holland has the great advantage of holding the mouths of the Rhine and the Meuse, or Maas, and the Schelde, or Scheldt. Her means of river communication with Germany, France and Belgium are numerous, and the possession of a length of 940 miles of canals and 340 miles of rivers enables her, apart from her railways, which have a length of 1,130 miles, to carry on her large trade with greater facility of transport than any other European country, with the exception, perhaps, of Belgium, her industrious little neighbor on her southern flank.

Owing to the great improvements that have lately been carried out at the new mouth of the Maas at the Hoek of Holland, 18 miles from Rotterdam, vessels drawing 22 feet can already reach that port, and works are now in progress for the further improvement of the Lower Maas, which, when completed, will bring the total expenditure up to £2,500,000. Of the 3,765 vessels that made use of the new channel in 1884, 70 had a draught of from 20 to 21 feet, and 10 of from 21 to 22 feet.

By means of the North Sea and Amsterdam canal, a full account of which will be found in Mr. Hayter's paper on that great work, vessels drawing from 23 to 24 feet are able to reach Amsterdam direct from the sea by a channel 15 miles long, and from 65 to 105 feet wide at the floor line. This canal, which cost upwards of £3,000,000, and for which Sir John Hawkshaw was Consulting Engineer, and Mr. J. Dirks, Resident Engineer, has now almost totally superseded the third and earliest great maritime highway of the Netherlands, namely, the North Holland canal, 52 miles long and 16 feet deep, from the Texel to Amsterdam. This, the greatest work of its day, was constructed in 1819–25 by Blanken, at a cost of nearly £900,000.

The inland canals of Holland, which serve as arterial drains as well as for navigable purposes, are generally 60 feet wide at the bottom and 6 feet deep. In places where their extremities are connected with the sea, they are closed by massive flood-gates to keep it out when it rises higher than the canal. It is worthy of remark that within the natural sand dunes and artificial dykes which protect the coasts of Holland and Belgium from the encroachments of the sea, not only is the surface of the canal but the bed itself frequently many feet above the level of the surrounding reclaimed land; and it is an interesting fact that the surface-level of the North Holland canal between Buiksloot and Purmerend is 4 feet below mean sea-level.

Through the kindness of Mr. J. Dirks, M. Inst. C. E., Engineer-in-Chief of the Waterstaat, I am able to direct your attention to a very interesting map of the Low Countries which he lately forwarded to me "with the object of explaining," to make use of his own words, "our singular but historic system of nomenclature, our rivers being cut up into longitudinal pieces like an eel."

### Belgium.

The surface of Belgium is generally level, and it is only towards the south-east that one finds a wild tract of country of small extent, but with elevations sometimes attaining a height of 2,000 feet. The principal rivers of Belgium are the Meuse and the Scheldt.

The Meuse rises at a level of 1,350 ft. above the sea, near Langres, in France, enters Belgium about 30 miles south of Namur, and on reaching that town receives its largest tributary, the Sambre, which almost doubles its volume. From Namur the course of the Meuse trends to the north-east, and continues in that direction to Venloo, passing Liege and Maestricht on the way. From Venloo it takes a north-west direction to Gorcum, where it joins the Waal branch of the Rhine. Its further progress to the sea is difficult to pronounce in a few words, and can be best understood by reference to Mr. Dirk's map. The total length of the Meuse, which is canalized at different places, is 580 miles, of which 460 miles are navigable.

This, by far the most important river in Belgium, although its basin has an area of only 8,000 square miles, derives its origin in France, 10 miles north of St. Quentin, at an altitude of 360 feet above the sea, and is navigable for more than four-fifths of its course. On arriving at Ghent, where it receives its chief tributary, the Lys, the tidal influence is first felt, and on reaching Antwerp the mean range of the tide is 13 feet 8 inches. At the mouth of the estuary (Flushing) the mean range is nearly 2 feet less, or only 11 feet 9 inches. According to information which I received on the spot in 1867, when charged by the British Government with a mission concerning an international question of engineering connected with the Scheldt, the scouring power of the tide at Antwerp is nine times greater than that of the fresh-water flow, the mean discharge of the latter being only 5,000 cubic feet per second over a width of 1,200 feet. Hence the great depth of the river at Antwerp of 24 feet at extreme low water alongside its noble range of commercial quays, which, for extent and accommodation are unrivaled in any other port with which I am acquainted. Thanks to its unique position at the head of a tidal estuary, which, like the Thames, has no bar at its mouth, to the abolition of the Scheldt dues, and above all to the foresight and liberality of the Belgian Government, which has spent £4,000,000 sterling on dock and river works since 1877, Antwerp has now become in many respects the foremost port of the continent of Europe.

Besides her 700 miles of navigable rivers, and 2,634 miles of railways, Belgium possesses a length of about 540 miles of canals, by means of which an excellent system of water communication exists between all the large towns and the chief sea-ports of the kingdom. By these artificial waterways, also, there is easy and cheap intercourse with Holland and with the chief towns in the north of France. On the authority of Mr. Von Borries, the cost of canal carriage from the Belgium coalfields to Paris was 0.29d. per ton-mile in the spring, and 0.34d. in the autumn of 1883, without paying interest.

## REPORTS OF ENGINEERING SOCIETIES.

Engineers' Club of Philadelphia—*Record of Regular Meeting, June* 5, 1886.—Mr. J. E. Codman presented a paper on Calorimetric Tests of Boilers, from which the following paragraphs are taken:

Tests, for the quality of steam furnished by three different forms of boilers, in common use in Philadelphia, were made for the purpose of obtaining data to be used in the selection of additional boiler capacity.

The apparatus used for determining the quality of steam was a wooden barrel, large enough to contain about 230 lbs. of water, constructed for the purpose, the depth being considerably more in proportion to the diameter than usual. The steam pipe was carried to the bottom of the barrel, and a number of small holes drilled in the side, the end being plugged up. A side attachment was made by which the steam could be blown through the pipe, before turning into the barrel. The barrel was placed on a scale weighing to $\frac{1}{4}$ ounces, and 200 lbs. of water and 10 lbs. of steam used.

The temperature was taken with a Centigrade

thermometer graduated to $\frac{1}{10}$ degree. Observations were taken every fifteen minutes, and the condition of the fires, running of the engine, and other notes were made at the same time. It was found that the loss from radiation of the mixture was inconsiderable, as the temperature did not fall more than $\frac{3}{10}$ of a degree, Centigrade, in five or six minutes.

The first series of tests was made on the plain cylinder boilers, 30 ft. long and 4½ ft. in diameter, to the bottom of which were attached two mud drums, 22 ft. long and 28 in. in diameter. Boilers and mud drums were set in brickwork, and externally fired. The quality of steam obtained from these boilers varied greatly according to the condition of the fires and height of water in boilers. The greatest per cent. of moisture obtained was 17 per cent., with fresh fires and the water above the average height, reducing the steam space 30 per cent.

The second series of tests was made on what is commonly called the double-deck form of boilers. The lower cylinder was 6 ft. in diameter and 12 ft. long, containing ninety-two four-inch tubes. The upper cylinder 4 ft. in diameter and 13 ft. long, connected to the lower cylinder by three necks 14½ in. in diameter and 9 in. long. Boilers and drums were set in brickwork and externally fired. The heat and flame passed under the lower cylinder and through the tubes to the front of the boiler and returned under the upper cylinder to the stacks.

Samples of steam for the tests were taken out of the 14-inch main steam pipe leading to the engine, about 60 ft. from the boilers. The attachment for samples of steam was made with a 1½-inch pipe, about 12 inches long, cut in half longitudinally, tapped into the side of the steam pipe and carried inside so as to reach nearly across the pipe.

A 1½-inch stop valve was placed in this pipe, about 8 inches from the outside of the main steam pipe. Beyond this, the pipe was reduced to one-half diameter, and continued to the barrel. Tests were made every fifteen minutes during the day, and a sufficient number were taken under the varying conditions of cleaning fires, high and low water, and high and low steam, to give a fair sample of the average quality of the steam furnished in the ordinary working of the boiler.

It was noted that in no case was the change of condition in the boiler followed immediately by a change in the quality of the steam, an interval of from 30 to 45 minutes elapsing before the steam changed. This was, no doubt, due to the fact that the boiler capacity was far in excess of the amount required to run the engine.

The third series of tests was made on the marine tubular boilers, 10 ft. 10 in. long and 11 ft. 6 in. in diameter, containing two corrugated furnace flues and 188 3-inch tubes, with one steam drum 3 ft. 6 in. in diameter and 12 ft. 6 in. long, connected to two boilers. These boilers are internally fired and so arranged that the escaping gases pass off through the tubes, and under the drum, before entering the stack. Ten boilers were running and supplying steam for two 15-million gallon Worthington pumps.

Steam for samples was taken from the main steam pipe, about 15 ft. from the boilers and connection was made with a 2-inch pipe, and stop valve, reduced to ½ in. about 2 ft. from the main pipe and continued to the barrel. Steam from these boilers was found to show but slight variation, ranging from 9 to 6 per cent. of moisture.

The average of all the tests for each kind of boiler was found to be, for the

| | |
|---|---|
| Cylinder | 4.05 per cent. |
| Double-deck tubular | 4.66 " |
| Marine tubular | 6.91 " |

Comparing the results as given in the annexed table, it is found that the cylinder boilers, driving to their full capacity, still furnished a fair sample of steam; while the double-deck boiler, doing only one-third capacity, furnished an average quality of steam; and the marine boilers, doing nearly the full capacity, furnished steam containing 2¼ per cent. more moisture than either of the other two furnished.

Comparing with the evaporative efficiency of 5 lbs. of water per pound coal at given pressure and temperature for the double-deck and 6.3 for the marine boilers, and allowing for the 2¼ per cent. more of moisture in the steam, the marine boiler will give 24 per cent. better results than the double-deck.

Comparing this with amount of work performed, it is found the marine boilers were doing 43 per cent. more work, showing an advantage in favor of the internally fired marine boilers, both in evaporative efficiency and quantity of steam furnished. In comparing the amount of steam furnished by each kind of boiler, the steam was computed from the indicator cards for double-deck and marine boilers, taken from the engines running at the time the tests were made. This, therefore, accounts for the small figure of evaporation given in the table, as only about 75 per cent. of the steam can be accounted for by the indicator card. For the cylinder boilers it is from the actual amount of water weighed and pumped into the boilers. Therefore, no comparison on the same basis can be made with the other boilers.

COMPARISON OF RESULTS BETWEEN MARINE AND DOUBLE-DECK BOILERS.

| | Per cent. |
|---|---|
| Difference in favor of double-deck boiler in quality of steam | 2.25 |
| Difference in favor of marine boiler, in economic evaporation in pounds | 1.25 |
| Less, 2.25 per cent. for moisture in steam pounds | 1.22 |
| Per cent. in favor of marine boiler, in economic evaporation | 24. |
| Difference in favor of marine boiler, in water evaporated, per sq. ft. of heating surface, in lbs. 0.4 per cent. | 43. |

*Note.*—Same quality and size of coal used under all the boilers during the tests.

The Secretary presented, for Mr. G. R. Henderson, an article on the Taper of Steam Jets, issuing from circular orifices. Outlines were obtained by photographing different jets against dark back-grounds, and where they were sheltered from the wind, and measuring the angles

on the photographs. The following results were obtained:

With $\frac{1}{4}$-inch nozzle and 95 lbs. pressure, the half-angle was 11° 19′; $\frac{1}{2}$-inch nozzle, 95 lbs., 11° 39′: $\frac{3}{4}$-inch nozzle, 95 lbs., 13° 5′; $\frac{1}{4}$-inch nozzle, 145 lbs., 12° 4′; $\frac{1}{2}$-inch nozzle, 145 lbs., 10° 54′; $\frac{3}{4}$-inch nozzle, 145 lbs., 11° 27′. It will, therefore, be seen that the greatest difference between any two was little over 2°, the $\frac{3}{4}$-inch nozzle at 95 lbs., and the $\frac{1}{2}$-inch, at 145 lbs., giving the maximum and minimum angles respectively. Inspection of the results also shows that the angle does not seem to vary according to any law relatively either to the pressure or size of nozzle. Taking the mean of the two extremes, we have an angle of 12°; the *average* half angle of the six experiments, gives 11° 44′, or, as the tangent of this angle is about .2, we may call the taper of the sides of the cone, 1 in 5.

Mr. Henderson acknowledges the assistance which Mr. W. E. Hall rendered him in making these experiments.

*June* 19.—The Secretary presented, for Prof. L. M. Haupt, the following:

"*Whereas*, It is proposed in the United States Senate to add an item to the River and Harbor Bill, amounting to one million dollars, for the purpose of beginning the work of improving the entrance to New York Harbor in accordance with the specific plan, approved by a Board of Engineers as stated in Ex. Doc. No. 78, House of Representatives, 48th Congress, 2d section; and

"*Whereas*, The plan as proposed involves a large expenditure of time and money, and is uncertain in its results, and

"*Whereas*, We believe the limitation of the expenditure to a specific plan would not produce the desired end in the most expeditious manner, it is therefore

*Resolved*, That in view of the general importance of radically improving the entrance to the harbor of New York, in the most expeditious, economical and effective manner, we would respectfully request our Honorable Senators and Representatives in Congress to urge the appropriation of the amount desired, but only on the condition that its application be not restricted to any special plan, but be opened to all competitors, upon plans to be subject to the approval of the Chief of Engineers, or of a Board of Engineers to be appointed by him."

With reference to the motion to adopt the resolution, Prof. Haupt called attention to the uncertainty, expense and great length of time which would be required to carry out the plan of the stone dyke from Coney Island, and stated that he believed the result would be merely to create a second contraction, similar to that existing at the "Narrows," with deep water at the exit, but that beyond there would reform a bar with not more than the present depth of water. The plane of tidal scour is limited, at that locality, to 24 feet, and unless some device be used to maintain an increased *bottom* velocity at ebb tide, he predicted failure. The dyke would violate a fundamental principle of harbor construction, by opposing great resistance to the flood wave, and hence diminish and weaken the ebb discharge, causing a shoaling in the lower bay and a cutting off and destruction of the northern channels. It would also render existing "aids to navigation" (lighthouse, etc.) useless.

He reaffirmed his opinion as to the practicability of utilizing the forces, acting so powerfully at the head of Gedney's Channel, to open and maintain the same, and believed it should be attempted by other means than by dykes or by dredging, before Congress committed itself to the plans proposed.

On motion of Mr. E. S. Hutchinson the preamble and resolutions were unanimously adopted.

The Secretary presented, for Mr. H. K. Lee, a table of Sizes of Chimneys, for the Reference Book.

The Secretary presented, for Mr. Fred. Brooks, C.E., of Boston, a table of Approximate Metric Equivalents, for the Reference Book.

The Secretary presented a letter from Captain Spencer C. McCorkle, wherein he states that the Superintendent of the U. S. C. & G. Survey had given his assent to the presentation to the Club, for publication and discussion, of the investigation which Captain McCorkle has made of Movement of Ice in the Delaware River in 1886.

Captain McCorkle was present and explained the scope of the paper and specially desires free and full discussion thereof.

Mr. Gratz Mordecai, author of a report on Railroad Terminal Facilities at New York, presented "Notes on the Investigation of the Movement of Freight and Passengers in Cities," and exhibited a large map—about 6′ × 10′—showing New York City and surroundings from Eighty-sixth street on the north, to Erie Basin on the south.

He said: "There is a great amount of information about every city scattered in its different public offices and in those of various corporations and firms, and my desire was first to combine and make all this information intelligible. I knew that every department of the city government was thoroughly acquainted with its specialty, and that the insurance companies, the directory men and many others had done what we would call—out in the country—an enormous amount of "field work," and that their field books were to a very large extent available. My first step was to get a 400 ft. scale map of the city, and I fortunately found one almost exactly to that scale, showing, however, only the streets. I converted to the same scale the different maps I found, in surrounding cities in the offices of the railroad companies, of the U. S. Engineers, the Dock Department and other sources, and in that way I compiled a fairly accurate map to that well approved scale for preliminary work, showing, in some detail, yet in a comprehensive way, the streets, street railroads, docks, railroad yards, tracks and facilities, freight houses, city markets, &c.

My next desire was to show something about the freight centers and the location, growth and concentration of the various trades. I placed on the original map the house number at the corner of every street (which was given in the directory); and from the business direc-

tory, taking the different trades and manufactures separately, I made lists of the numbers at which they were located on every street, and by this means located them on my lap, which shows, in different colors, the location of the retail dealers in food and manufactures, of the wholesale dealers in food and manufactures, and fixes the location of some of the various trades and freight centers, by special marks and numbers.

Appreciating that a city is both a center of consumption and a center of distribution, and knowing that an investigation of the movement of freight depends, for one thing, upon a knowledge of the local consumption, which must depend in part upon its population, I made my estimates of population (permanent and floating) in every ward of the city, and from them made an approximate estimate of the average daily movement of freight for local supply, and incidentally (from the reports of the different city railway companies) of passengers, and some of the approximate figures are given as follows:

Average daily passenger movement—1884, Elevated, 265,000; Surface, 505,000; Total, 770,000, or fully one-half the permanent population.

Average daily tonnage of freight (food, clothing, coal, etc) delivered directly to consumers south of Eighty-sixth street; 1885, 13,300 tons; 1895, 17,200 tons.

To be sure this movement varies in amount with the seasons, and these figures are only intended to give some idea of the average daily movement of freight for local supply to one destination.

I did all this work simply from my own personal desire to see what could be done, and doing it, as I did, without authority, my results, to be sure, are incomplete and my maps hardly more than begun, but I determined to my satisfaction,

1st. That it is possible to collect and combine in this way information of great value for the growth and prosperity of a city, and for the enlargement of its conveniences for works such as docks, railroads, markets, freight houses and other works.

2d. That an engineer, by patient investigation and the aid of such a map, combined with such detailed maps as the insurance maps, could make a most valuable report upon the methods and cost of handling, distributing, storing and selling the necessaries of life and the principal articles of trade.

3d. That the practical uses of such a report would be in the regulation of cities and corporate laws and in determining the location of public works and improvements

Here followed some general remarks upon the responsibility of the engineer in regard to "location" and the different influence he exerts in "country" and "city" work, as instanced in the cases of the N. Y., W. S. & B. Ry. through central New York and the Elevated Railroads in New York City.

"I cannot help closing with the plea that you do something to prevent the public convenience from being handed over, in an economic and engineering regard, to pecuniarily interested parties, and also to establish the rule that public franchises of all kinds for industrial purposes, should be reported on, not only by a corporation attorney, but also by a corporation engineer; for no matter how bright, far-seeing and progressive the promoters of new enterprises may be, it would seem that in public matters they should be officially controlled and aided by your experience and deliberate methods of study."

## ENGINEERING NOTES.

What is regarded as an engineering feat was accomplished a few days ago on the Great Western Railway, between Worcester and Hereford. The communication between these two cities was destroyed by the washing away of a large brick bridge over the river Tame, but within four days a temporary wooden structure of 65 ft. span had been erected, from the designs and under the superintendence of Mr Armstrong, C. E., of Hereford.

Messrs. Oldham and Richards, of Manchester, have just patented a new pulley for driving planing machines, which requires no strap fork, and takes the place of the three pulleys usually required for driving, reversing, and loose running. This is effected by carrying within the pully a couple of friction cones actuated by a lever from the machine. The pulley itself constantly runs loose, and as the machine has either to be driven or reversed, one or other of the friction cones is brought into action. By this arrangement the driving strap constantly remains on the one pully, and a considerable saving of wear and tear is effected, whilst there is no loss of time in stopping the machine for changing the strap from one pulley to another, and the driving gear is brought within smaller compass.

A Big Crane.—A large steam crane, capable of lifting and manipulating weights up to 100 tons, has just been erected at the Alexandra docks, Hull. This is the most powerful steam crane possessed by any dock company in the United Kingdom. It has been satisfactorily tested with a load of 103 tons, in the presence of Messrs, James Taylor & Co., of the Britannia Works, Birkenhead, the makers of the crane, and of Mr. Hurtzig, C. E., the engineer, on behalf of the Hull and Barnsley Railway and Dock Company, to whose order the crane was constructed. After lifting and revolving with 103 tons, it was the next day put to a number of severe tests with a load of 65 tons, raising it at the rate of 6ft. 6in. per minute, and making a complete revolution—that is, the load passing through a distance of 283 ft. in 6 min. 50 sec. This powerful crane is an important addition to the appliances of the dock, which having a fine entrance and deep sill, is now not only well suited to the large steamers engaged in modern commerce, but is fitted for the reception of the ships in Her Majesty's service, and to deal with the shipment and unshipment of their heavy guns, boilers, &c, in an expeditious manner. It will enable shipbuilding firms of the port to compete for

Government work on equal terms with other ports, and will probably be first brought into use by Messrs. Earle's Shipbuilding and Engineering Company, who have commenced work on H. M. S. Malabar, having secured the contract for the refitting of that ship. The very large and heavy boilers of the belted cruiser Narcissus, now being built at Messrs Earle's works, will also be shipped under this crane. The crane is worked by steam power, steam being supplied by a steel boiler of Taylor's vertical type, tested with a pressure of 120 lbs. The head of the jib is 61ft. above the water level of spring tides, and has an out-reach of 29ft. from the face of the quay. The main features of construction are in the arrangement by which the center post common in cranes gives place to a large central pin, only subject to direct upward tension, the whole crane acting as a lever to raise it vertically. The jib, which is of the double cylindrical type, is of steel, while steel and wrought iron predominate in the structure throughout. Four sheaves, each 3ft. in diameter, are carried at the head of the jib, where the two steel tubes composing it meet. The load is suspended from the jib by eight falls of steel wire rope, composed of 222 wires, with a hemp core. The hoisting is effected by means of a large spirally-grooved barrel, taking the wire rope. There are two speeds of lift, the hoisting engines being horizontal, with double cylinders 12in. in diameter and 16in stroke. The two are for 100 tons and 50 tons respectively. For revolving, there is a pair of small vertical engines, actuating two sets of worm gear, one on each side of the crane, and two pinions which work into a large circular rack attached to the turned roller path. The fulcrum is the "live ring," containing sixty rollers, running on the cast iron and steel roller race on the top of the stone work. Ten or eleven of these rollers take the thrust at the foot of the jib at a time, constantly changing as the crane revolves, and the resistance is the weight of the masonry, secured by six massive, radiating, holding-down bolts, by which the center casting and pin are anchored. All the valves and levers connected with the crane are within easy reach of one attendant. The body of the crane is constructed of wrought-iron plates and framing, and is of great strength The whole is carried on a substantial foundation of masonry and concrete. The load trial consisted of 100 tons of steel rails, exclusive of the heavy slings by which they were suspended. The movable block and swivel is a very nice piece of workmanship, and it was quite easy for three men to twist round the heavy load while suspended. On the whole, this fine piece of machinery reflects great credit on the makers, and a finer crane does not exist in any port in England.—*Engineer*.

## IRON AND STEEL NOTES.

An Antique Iron Helmet. — Two or three years ago some peasants digging near the banks of the Danube, on the Hungarian side, opposite to Belgrade, turned up a most beautiful and finely-preserved iron helmet. which, it will interest archæologists to learn, is neither more nor less than a *chef d'œuvre* of antique Greek work, of probably three or four centuries before Christ. It is scarcely necessary to say that works in iron of antique Greek or Roman origin other than corroded and scarcely recognizable fragments are of the utmost rarity. The specimen in question is in a wonderfully perfect state, scarcely, indeed, less so than that of a finely patinated bronze. It seems that it was found in the midst of wind-blown hillocks or dunes of dry, shifting sand; hence, probably, in some unexplained way, its exceptional state of conservation. Whether or not the skull of the wearer was found within it does not appear, but the helmet is in the shape of a complete head, the face, hair, and beard admirably modeled in *repoussé* or hammered work, finished with the chasing or graving tools in the most exquisite style. It represents a young warrior of about twenty-five or thirty, with an incipient beard and moustache—a Paris, rather than a Hector or Achilles; the eyes are open for the wearer to see through, and the lips are parted, leaving in like manner an aperture for respiration. Contrary to the arrangement of mediæval helmets, the upper part, or scalp, forming a skull cap – not the mask or visor—is hinged and movable, and it oversets the face. It was made to fit rather close to the head, probably leaving room only for a lining or padding of some soft substance, and it represents the natural hair of the wearer in finely-disposed, crisp locks. There is, however, at the summit, a small socket, evidently intended for a plume or some other ornament. The lower margin at the back of the scalp or skull cap is pierced with small holes, whence, probably, chain mail, to protect the back of the neck was originally attached. There are, however, no remains of ringed mail remaining The substance of the iron or steel is comparatively light and thin, but by no means flimsy or unsubstantial. In this respect, and also in some others, the helmet is not unlike certain steel Japanese helmets which have been brought to England of late years. These last also have visors in the form of human faces or masks, but they are always of wild, grotesque, and forbidding types. The Belgrade helmet, on the contrary, embodies a perfect ideal of classical Greek beauty.—*Bulletin*.

The Sampling of Pig Iron.—The question as to the best manner of obtaining a perfectly true average sample of pig iron, &c., for analysis, is one that has called for much attention from all chemists of iron and steel works, and on which a variety of opinions are held. An interesting and instructive paper on the subject was read at the meeting of American Mining Engineers, at Pittsburg, by Mr. P. W. Shimer, and from it the following notes are abstracted: If we take a sample of pig iron in the form of borings, such a sample consists of a mixture of particles of pig iron, with more or less finely-divided particles of graphite which has been separated from the iron during the boring. The amount of graphite thus present is in nearly all cases large enough to cause great difficulty in so thoroughly mixing the sample as to insure obtaining a perfectly uni

form and average portion for the actual chemical determinations; because such mixing is hindered by the great difference in weight, and also in size, between the particles of iron and those of graphite. Attempts were made to lessen this source of error by having the borings taken as fine as possible, so that the particles of iron should not be larger than those of graphite But this was not successful, as so much of the graphite was in the form of the finest powder. Duplicate determinations of carbon on samples so prepared, executed with the greatest possible care, always gave differences too large to be explained in any way, except by the inequality in the sampling. Nor were better results obtained when large borings were used, in the hope that the graphite which was detached from them during boring would be too small in amount to affect the results. It was not found possible to obtain a proper mixture in any of the several methods of mixing which were tried. The differences were sometimes as large as 0.2 per cent. A plan was finally used which gave satisfactory results in all cases. The borings are carefully placed in a small porcelain crucible, or in a dish, and are thoroughly moistened with alcohol. For thirty grammes of borings two cubic centimeters of alcohol are required. The borings are then well mixed for some five minutes. The alcohol serves the purpose of making the graphite adhere to the iron during the time of the mixing. After mixing, the requisite portion for the actual weighing is taken out, dried, and weighed. It is stated that portions taken in this manner are always a true sample of the whole lot of borings, and give excellent results as to agreement, the differences between two determinations not exceeding 0 03 per cent.

## RAILWAY NOTES.

In proportion to population, the greatest rate of railway increase since 1880 has been in Australia, but its mileage is still small, as is its population. In Europe nearly one-fourth of the railroad built since 1880 is in France, which has increased its mileage 3121 miles, or 19.2 per cent., in the four years. In proportion to population, it has now a larger mileage than any other European country except Sweden, Switzerland, Denmark, and Great Britain and Ireland. In proportion to area, it is behind Belgium, Great Britain and Ireland, Holland, Germany, and Switzerland.

The East Indian Railway Company has 1,036,527 iron plate, 178,313 iron bowl sleepers, and 2947 lineal yards of wrought iron sleepers. Of wooden sleepers, the company has down 3,073,559. The average age of all the sleepers in the roads at the middle of the last half of 1885 was 10.55 years. The permanent way of the East Indian Railway is laid with 2155 miles of double-headed rails weighing 82 lb. per yard, 1217 miles weighing 74 lb. per yard, and 1310 miles of steel rails weighing 75 lb. per yard. The average age of rails in way at the middle of the half-year was about sixteen years.

The construction of the Scinde-Hagar strategical frontier railway, British India, is making rapid progress. A section ninety miles long has been laid from Shen Shah, opposite Mooltan, on an alignment parallel with the left bank of the Indus. The rails are being laid at the rate of three miles daily. The Scinde-Pishin railway will, it is said, owing to financial pressure, not be carried for the present past Shah-Ahmed, the site of the proposed entrenched camp, but an iron bridge will be thrown across the Lora river in front of that position It is possible that the delay may prove beneficial if it has the result of procuring more thorough examination than has yet been made into the respective merits of the tunnel scheme and of the Khojah alternative route by Muskhi, which, although longer, would avoid the difficulties of the Khojah range.

## ORDNANCE AND NAVAL.

On the Deformation of the Bore of a Gun in the Region of the Obturator, and the Resistance of the Breech Block.—In an article with the above title the Author considers these questions. Few authors have dealt with the subject, and the theories of General Gadolin, published in the Russian Journal of Artillery in 1868, and an article by Captain Duguet, published in the Revue d'Artillerie in 1877, are reviewed and criticised.

The first-named treated the subject fully, and recommended the employment of hoops with longitudinal locking, to counteract the tensile strain exerted by the breech-screw on the interior wall of its seating; he also considered the deformation of the bore around the obturator. The general confessed himself unable to completely solve the problem, in the presence of the difficulties of analysis which presented themselves and moreover was obliged to rely on certain hypotheses which the author considers to be contrary to the truth. Thus he admits that the strain, transmitted by the screw to its nut, is spread uniformly over its whole length, and that the pressure produced by the outer hoop in the longitudinal direction is entirely transmitted through the whole thickness of the metal above the seat of the screw. He shows, it is true, that in the nut the greatest strain takes place on the first thread, but the Author considers that the formulæ given in the article are inaccurate, as he proceeds to show.

Captain Duguet, whilst taking accurately into account the conditions which occur in a piece submitted only to longitudinal strain, gives no results of calculation, and refers to the Russian article.

Considering, then, that the results up to the present time, as obtained by analysis, are very incomplete, no doubt from the difficulty experienced in the application of Lane's formulas, the Author, from recent researches, believes that he is in a position to treat the subject more accurately, and divides his study into three parts. (1) Is devoted to the establishment of new formulæ. (2) Treats of the question of deformation of the bore. (3) The resistance of the breech-block.

Having established new formulæ of displace-

ment, the Author proceeds to apply them to the consideration of part 2, for which he takes the case of a hollow cylinder, submitted to internal pressure, and closed at the ends by two plugs independent of the cylinder. One plug is considered as the projectile, the other as the obturator, which may be a steel cup, or the De Bange form. In the former case the pressure acting on the inside walls of the cylinder tends to increase its diameter, and if the cylinder be indefinite, the walls would be expanded in a line parallel to themselves; but by reason of a portion of the cylinder being behind a certain point D situated at the obturator, which portion is not submitted to any internal pressure, the line of expansion near the obturator will not be parallel to the line of the wall of the cylinder, but curved from the point D to a point A on the parallel line of expansion.

The length of this curve will depend on the interior pressure $P_1$, the original radius $r_0$, and the expanded radius $r'_0$ which is a function of the thickness of the cylinder by reason of the external radius $r_1$ and the pressure $P_2$ exerted on its surface by the hooping. Consequently the deformation will be so much less for a determined pressure $P_1$, as $r_0$ is less, $r_1$ greater, and $P_2$ still greater.

If the obturator were completely elastic, transmitting wholly the pressures in every direction, like liquids, over all its thickness, the curve of bending would have its origin at a point a little behind the obturator, but as it only transmits a portion of the pressure, the point D is taken as in a line with the front face of the obturator.

In the case of the De Bange obturator the point D is changed, because the elasticity of the pads allows the better transmission of the pressure, and it is probable that D is behind the same point with the cup form of obturator, it is taken as at half-way up the pad. Applying these considerations to the case of a gun, where the obturator is not only a gas-check but is firmly attached to the breech-block, the Author gives a diagram showing the theoretical deformation of the breech end, and applies the formulæ of elasticity to the determination of the form of the curve produced in the bore by the pressure $P_1$, from which he deduces the argument that, if the breech of a gun be hooped only in front of the obturator, the tendency to deformation in the seating of the breech-screw would be reduced as the pressure $P_2$ of the hoop would diminish the value of $r_0$. Other considerations compel hooping behind the obturator; so under these conditions, strictly speaking, a variable grip in the hoops, increasing in strength towards the section of the metal in front of the obturator should be given.—*Revue d'Artillerie.*

## BOOK NOTICES

### Publications Received.

Proceedings and Papers of the Institution of Civil Engineers:

No. 2070. The Theory of the Indicator and the Errors in Indicator Diagrams, by Osborne Reynolds, F.R.S., LL.D.

No. 2071. Experiments on the Steam Engine Indicator, by Arthur William Brightmore, Stud. Inst. C. E.

No. 2139. Injurious Effect of a Blue Heat on Steel and Iron, by C. E. Stromeyer, Assoc. M. Inst. C. E.

No. 2143. Blasting operations at Hell Gate, New York, by L. F. Vernon-Harcourt, M. Inst. C. E.

No. 2150. Water Purification, by Percy F. Frankland, Ph.D., F.C.S.

No. 2152 The Granada Earthquake, by Edward J. T. Manby, M. Inst. C. E.

No. 2184. English and American Railroads Compared, by Edward Bates Dorsey, M. Am. Soc. C. E.

Student's Paper, No. 200 Recent Researches in Friction, by John Goodman, Stud. Inst. C.E.

Abstracts of Papers in Foreign Transactions and Periodicals.

Transactions of the American Institute of Mining Engineers. Vol. XIV., June, 1885, to May, 1886.

Standard Practical Plumbing. By P. J. Davies. Vol. I London: E. & F. N. Spon.

This is simply an encyclopedia of household plumbing fixtures, and is made to include the processes of such adjustment to the dwelling as calls for the work of the artisan.

Most of the modern improvements are described and illustrated by good cuts, fully two thousand being employed in the book.

Of course such a volume (quarto, 360 pages) practically includes a complete treatise on sanitation of dwellings.

Monographs of the United States Geological Survey. Vol. IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey. By Robert P. Whitfield. Washington: Government Printing Office.

This is one of those additions to the literature of Paleontology, which students of Geology in all parts of the world will gladly welcome

A sketch of the geology of the Cretaceous and Tertiary Formations of New Jersey begins the work, and will be read with interest.

Then follow the descriptions of the fossils in the order of their age.

The full-page plates, thirty-five in number, which illustrate the descriptive text are of that high degree of excellence that has of late excited the admiration of students abroad.

Ditmar's Tables for Chemical Calculations. Second Edition. By W. Ditmar, F.R.S. London: Williams & Norgate.

This is a very useful book for analytical chemists. The new edition contains a chapter on Gas Analysis that was not in the first edition. A very few typographical errors in the former issue have been corrected.

Considerable space is very properly given to "Explanatory Notes," as the calculations frequently involve operations in which laboratory workers are not necessarily expert.

The Table of Formula Values is a valuable aid to such computations.

The work is beautifully printed, and the tables are in antique type.

THE LUMINIFEROUS ÆTHER. By DEVOLSON WOOD, C. E., M. A. Van Nostrand's Science Series, No. 85. New York: D. Van Nostrand.

That a scientist is ready to maintain that the all-pervading æther differs only in condition, rather than its nature, from the familiar forms of matter, is a fact of sufficient importance to insure a demand for this essay by students of physical science.

After quoting the views of eminent physicists regarding the properties which presumably belong to the æther, Prof. Wood says:

"We propose to treat the æther as if it conformed to the kinetic theory of gases, and determine its several properties on the conditions that it shall transmit a wave with the velocity of 186,300 miles per second, and also transmit 133 foot-pounds of energy per second per square foot. This is equivalent to considering it as gaseous in its nature, and at once compels us to consider it as molecular; and, indeed, it is difficult to conceive of a medium transmitting light and energy without being molecular. The electro-magnetic theory of light suggested by Maxwell, as well as the views of Newton, Thomson, Herschel, Preston, and others, are all in keeping with the molecular hypothesis. If the properties which we find by this analysis are not those of the æther, we shall at least have determined the properties of a substance which might be substituted for the æther, and secure the two results already named It may be asked, can the kinetic theory, which is applicable to gases in which the waves are propagated by a to-and-fro motion of the particles, be applicable to a medium in which the particles have a transverse movement, whether rectilinear, circular, elliptical, or irregular? In favor of such an application it may be stated that the general formulæ of analysis by which wave motion in general, and refraction, reflection and polarization in particular, are discussed, are fundamentally the same; and in the establishment of the equations, the only hypothesis in regard to the path of a particle, is—It will move along the path of least resistance." And furthermore, the author demands: "Granting the molecular constitution of the æther, is it not probable that the kinetic theory applies more rigidly to it than to the most perfect of the known gases?"

The analysis of the author leads to the conclusion that a medium whose density is such that a volume equal to twenty times the volume of the earth would weigh one pound, and whose tension is such that the pressure on a square mile is about a pound, and whose specific heat is such that it would require as much heat to raise one pound of it one degree (F.) as would be required to raise 2,300,000,000 tons of water the same amount, will satisfy the requirements of nature in being able to transmit light and heat 186,300 miles per second, and also transmit 133 foot-pounds of heat energy each second per square foot of surface normally exposed. This medium will be everywhere practically non-resisting and sensibly uniform in temperature, density and elasticity

Like its fellow volumes of the Science Series, it is of convenient size for the pocket, and of such type as to render its reading easy by the student while traveling.

ELECTRIC TRANSMISSION OF ENERGY. By GISBERT KAPP, A. M. I C. E. London: Whittaker & Co.

This is "a practical hand-book" *par excellence*—a book which will be read, studied, and used not by electricians merely, but by most engineers conversant with the English language. We would especially recommend this little treatise to those who are masters in matters appertaining to the mechanical transmission of power, for it is more than probable that electricity will soon take the most important place in the curriculum of experts in this particular subject Until recently, problems on the transmission of energy to great distance could be solved by three means, principally, viz., by the hydraulic, the pneumatic, and the tele-dynamic means; each of these has its peculiarities, advantages, and disadvantages. Sometimes one of these systems was found more convenient or more economical than another, but neither of the three modes is universally applicable. Electricity may in many cases supersede water and air as regards economy, it will outweigh rope-gearing in points of convenience; but it is destined to find employment under peculiar circumstances where none of the other modes of transmission have hitherto been considered suitable.

Practical examples there are in sufficient number, and if the subject has not received the universal attention it deserves, the cause must be found in the want of a sober, systematic treatise. The literature on the electric transmission of energy has, up till recently, been rather unsatisfactory. Elaborate papers were read before scientific bodies, but they were mostly too elaborate to be of practical value. M. Marcel Deprez and others attempted to startle the world from time to time by announcements that energy amounting to several horse-power has been transmitted through several kilometres of telegraph wire; such facts, and the attendant mathematical reasoning, were very interesting in their way for the moment; but they did not serve to convey to the industrial man's mind the full meaning which the experimenters attached to it.

Most of the attempts of transmitting energy electrically were by the general public regarded as experiments of a purely scientific nature, and of but small importance. The reports in periodicals concerning many examples were often couched in language unacceptable by the matter-of fact engineer, and they were seldom sufficiently intelligible for the student. What we wanted was a systematic treatise, giving us a concise outline of the subject; a book which would lead us up step by step to a clearer conception of the whole business: a book which would teach us not only what has been done by others, and how they *did* the thing, but how we should do it ourselves. Mr. Kapp's hand-book gives us more than that; it goes a long way towards indicating ways and means of doing things better than they have been done before; and we venture to say that his book, small as it is, will have a most beneficial influence upon

the immediate development of an important industry. We differ from Mr. Kapp on certain points, but we are bound to give him credit for excellency of style, systematic arrangement, and remarkable clearance of definition. The language of the author, to say the least, is lucid, and he displays a peculiar gift in the choice of happy illustrations; the first chapter, consisting of about 40 pages, contains the essence of modern ideas on lines of force, the relations between mechanical and electrical energy, and a capital explanation of the fundamental and practical units of measurements. The author's description of an "ideal motor" and an "ideal system of transmission" we thoroughly appreciate as giving the student in few words the characteristic outlines of a grand lesson; he will by a careful perusal of these pages get a clear notion of the elementary principles involved, and it will save him at once from drifting into that hopeless confusion which is so often produced in the brain of the student, young or old, by the reading of certain obsolete text-books.

The second chapter has some allusion to the historical development of electro-motors, but this only for the purpose of illustrating certain principles. Too much space seems to be devoted to the description of the original Siemens machine and the effects of the dead points in the "shuttle-wound" armature; no less than seven pages of descriptive matter accompanied by tables of tests with two Griscom motors are given to this discussion. The results of these experiments are of little value, in so far as this type of machine has never been of much use, unless as a toy, and we have sufficient evidence to believe that the author must be possessed of ample material of a more practical character. There is a passage on page 64 which we do not appreciate: it says, "If it be absolutely necessary to use a motor of that class, the field magnets of which are either permanent steel magnets or are electro-magnets excited independently, the waste can to a certain extent be prevented by inserting into the *armature current* an electro-magnet which will by its self-induction steady the current." The italics are our own; we assume that "armature current" is a misprint and should read *circuit*, but the whole explanation seems quite unnecessary, as no one would think of resorting to similar means in order to attain the ends indicated. If the author had carried out experiments (of a kindred nature to those mentioned on page 65 and tabulated at 66) with a couple of motors of a type and size wherein the *secondary* influences do not absorb 70 to 80 per cent. of the energy supplied at the terminals, then he would undoubtedly have modified certain general conclusions which were evidently based upon the results recorded. Supposing we run two rationally constructed motors in series with a given load, current, and speed, it does not follow that by joining the same motors in parallel and using half the E. M. F. we shall get the same current and speed. If the current were the same, then the speed should be greater than before, because the resistance of a pair in parallel must be one-fourth of that of the same pair in series; and we know that the influence of resistance upon the speed of series wound motors is very considerable.

We admire, however, Mr. Kapp's method of developing a practical theory of the dynamo or motor; his formulæ are intelligible, capable of being applied by anyone possessing an elementary knowledge of mathematics, and above all they are reliable; we have found them so, and we know of none better.—*The Telegraphic Journal and Electrical Review.*

## MISCELLANEOUS.

A New Constant Cell.—Mr. H. P. Laurie has devised a voltaic cell which he claims to be worthy of being considered a constant cell. It consists of a cadmium plate and a platinum plate; the exciting solution being of cadmium iodide with free iodine in it. The cadmium plate was, however revolved in the solution by clockwork at the rate of two or three revolutions per second. The electromotive force of the combination was about 1.076 volts. This is a convenient value for practical purposes as it is almost one volt. The movement of the plate appears to keep the electromotive force more constant, although the cell has been supplying a current, than if the plate had been kept still.

Conductivity of Resins.—M. Bartoli has ascertained that the ordinarily perfect insulators of the resin type become more or less good electrical conductors when heated to softness or melting, afterwards their conductivity increases with the temperature. A mixture of guaiacum with naphthaline, the latter a perfect insulator and of the same melting point as guaiacum- conducts much better than the resin alone, being much less viscous. Oxidised or acid constituents in the resin also increase their conductivity. Some always conduct very little, as Canada balsam, copal, mastic, and dammar; Chios turpentine, pitch, asphalte, colophonium, are moderately good conductors when soft or melted. Styrax, jalap, scammonin, dragon's blood, amber; the balsams of Peru, Tolu, and Copaiba; shellac, laudanum, aloes, myrrh, Venetian turpentine, are good conductors when melted.

A New Secondary Battery.—Herr Kalischer has devised a secondary element of iron and lead in a concentrated solution of lead nitrate. The iron anode is passive, and with currents not too strong becomes coated with coherent thick layers of black peroxide of lead, which protect the iron from contact with the liquid and from decomposition. The change is completed when gas is freely liberated at the anode, and the liquid gives only a slight precipitate with sulphuric acid. To prevent lead growths between anode and cathode, amalgamated lead in contact with mercury is used. In discharging, the peroxide becomes brown, and changes into monoxide, then into black peroxide. The electromotive force is from 2 to 2.5 volts, but sinks, when the current stops, to 1.8 volts. From its solubility in nitric acid the lead cathode must be occasionally replaced. Carbon can be used instead of iron.

VAN NOSTRAND'S

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## THE LUNAR SURFACE AND ITS TEMPERATURE.

By JOHN ERICSSON.

From "Nature."

A MONOGRAPH by the writer, relating to the temperature of the lunar surface, read before the American Academy of Science, September, 1869, contained the following:

"Are we not forced to dissent from Sir John Herschel's opinion that the heat of the moon's surface, when presented to the sun, much exceeds that of boiling water? Raised to such a high temperature, our satellite, with its feeble attraction, could not possibly be without an envelop of gases of some kind. Indeed, nothing but the assumption of extreme cold offers a satisfactory explanation of the absence of any gaseous envelop round a planetary body, which, on account of its near proximity, cannot vary very much from the earth as regards its composition. The supposition that this neighboring body is devoid of water, dried up and sunburnt, will assuredly prove one of the greatest mistakes ever committed by physicists."

This assertion was based on demonstrations showing that the circular walls of the great "ring mountains" on the lunar surface are not, as supposed, composed of "mineral substances originally in a state of fusion." The height and diameter of these walls being recorded in "Der Mond," computations based on the safe assumption that the areas of their transverse sections cannot be less than the square of their height, establishes the important fact that the contents of the wall of, for instance, Tycho, the circumference of which is 160 miles, height 2.94 miles, amounts $2.94^2 \times 160 = 1382$ cubic miles. The supposed transfer of this enormous mass, in a molten state, a distance of 25 miles from the central vent imagined by Nasmyth, and its exact circular distribution at the stated distance, besides its elevation to a vertical height of nearly 3 miles, involve, I need not point out, numerous physical impossibilities. Other materials and agencies than those supposed to have produced the "ring mountains" must consequently be sought in explanation of their formation. A rigid application of physical and mechanical principles to the solution of the problem proves conclusively that water subjected successively to the action of heat and cold has produced the circular walls of Tycho. The supposition that these stupendous mounds consist of volcanic materials must accordingly be rejected, and the assumption admitted that they are inert glaciers which have become as permanent as granite mountains by the action of perpetual intense cold.

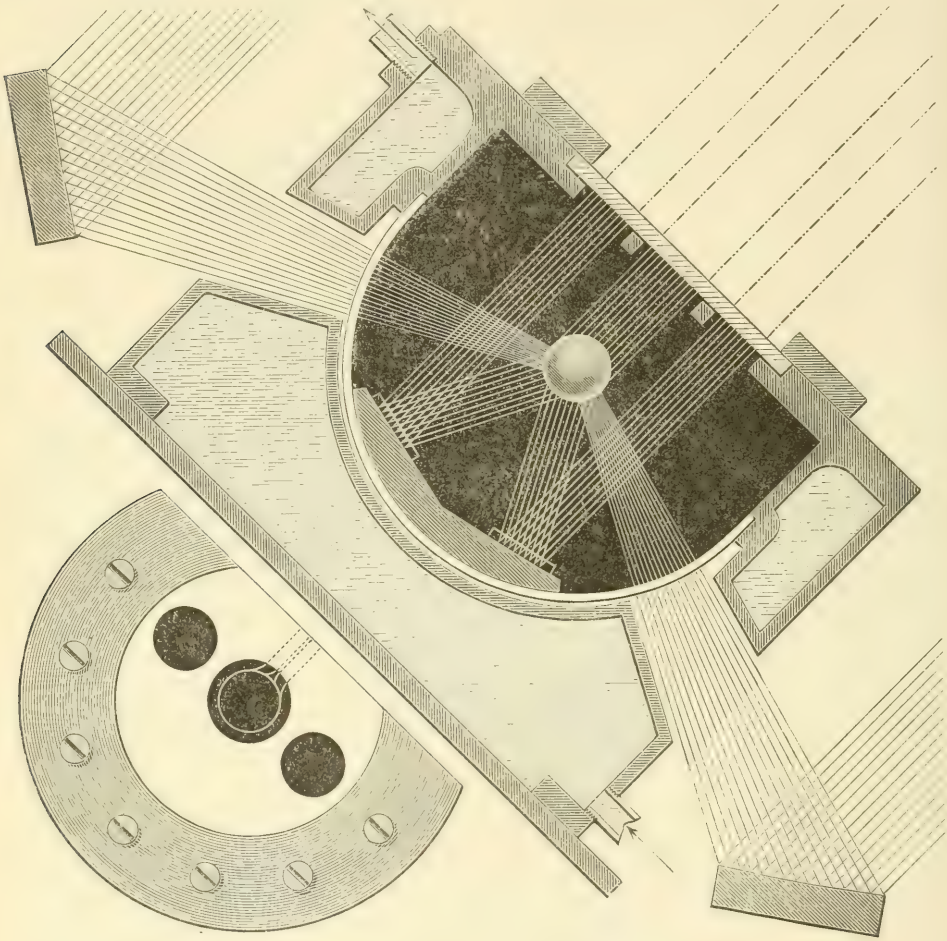
Independently of the foregoing demonstration, the fallacy of the volcanic hypothesis will be comprehended by its advocates on learning that the quantity of lava requisite to form the circular

walls of Tycho would cover the entire surface of England and Wales to a depth of 125 feet.*

Before proceeding further with our demonstration it will be necessary to establish the maximum temperature which solar radiation is capable of imparting to the lunar surface. This temperature, of course, varies with the distance of the primary and its satellite from the sun. By means of an actinometer the bulb of whose thermometer receives an equal amount of radiant heat on opposite sides, I was enabled to determine with desirable accuracy, sixteen years ago, that, when the earth is in aphelion, solar radiation on the ecliptic imparts a maximum temperature of 67°.2 F., and that the retardation of the radiant energy occasioned by the want of perfect atmospheric diathermancy reaches 0.207. Consequently the temperature produced by solar radiation at the boundary of the terrestrial atmosphere is

$$67.2 \times 1.207 = 81°.11 \text{ F.},$$

when the earth is in aphelion. Agreeably to observations during the winter solstice, compared with observations at midsummer, at equal zenith distance, the augmentation of solar intensity when the



Captain Ericsson's Pyrheliometer.

* Area of England and Wales, 58,320 square miles; contents of the walls of Tycho, 1382 cubic miles; hence $\frac{1382}{58320} \times 5280 = 125.12$ feet.

earth is in perihelion amounts to 5°.84 F.; hence the temperature produced by solar radiation reaches

$$81.11+5.84=86°.95 \text{ F.},$$

when the rays enter our atmosphere during the winter solstice. It should be observed that on theoretical grounds the increase of temperature, when the earth is in perihelion, will be in the inverse ratio of the *dispersion of the solar rays;* hence, as the aphelion distance is to the perihelion distance as 218.1 to 210.9, it will be seen that the temperature produced by solar radiation when the earth is in perihelion will be

$$\frac{218.1^2\times 67°.2}{210.9^2} = 71°.86 \text{ F.}$$

Adding 0.207 for retardation caused by imperfect atmospheric diathermancy, solar intensity during the winter solstice will be

$$71.86\times 1.207=86°.73 \text{ F.}$$

Calculation based on *observation*, as before stated, proves that the perihelion temperature is 86°.95, thus showing a trifling discrepancy between theory and observation.

Adopting 86°.73 as correct, it will be found that the yearly *mean* temperature produced by solar radiation when the rays enters the earth's atmosphere will be

$$\frac{81°.11+86°.73}{2}=83°.92 \text{ F.},$$

while the temperature produced by the sun's radiant heat is only 81°.11 during the summer solstice, as before shown. Hence the temperature of the lunar surfece when presented to the sun while the earth is furthest from the luminary can only be augmented 81°.11 F.

The remarkable fact that the moderate heat produced by solar radiation is cap able of increasing the temperature of bodies previously heated to a high degree demands consideration in connection with the subject under investigation; also the nature of the device, before referred to, for ascertaining the temperature produced by solar radiation. The accompanying illustration represents a combination of said device and a pyrheliometer differing materially from Pouillet's instrument, by showing the true intensity of the "fire" in the sun's rays.

The illustration presents a top view and a vertical section of the new instrument through the center line. The upper part, composed of bronze, is cylindrical with a flat top, the bottom being semispherical, composed of ordinary glass. The top of the cylindrical chamber is provided with three circular perforations covered by a thin crystal carefully ground and polished. A thermometer having a spherical bulb is introduced through the side of the chamber, the bulb being central to the transparent semispherical bottom. A short parabolic reflector, shown in section on the illustration, surrounds the instrument, adjusted so that its focus coincides with the center of the bulb of the thermometer. The compound cylindrical and spherical chamber is inclosed in a vessel containing water, appropriate openings at top and bottom being provided for maintaining constant circulation during experiments. Efficient means are also provided for exhausting the air from the internal chamber. The instrument is secured to the top of a substantial table which, during experiments, faces the sun at right angles by the intervention of a parallactic mechanism. Movable shades are applied, by means of which the sun's rays may be quickly cut off from, or admitted to, the parabolic reflector; while other shades enable the operator to admit or exclude the solar rays from the circular perforations at the top of the exhausted chamber. It will be readily understood that the parallel lines within the exhausted chamber, shown on the illustration, indicate the course of the solar rays passing through the crystal and the perforations at the top, while the converging radial lines indicate the rays reflected by the parabolic reflector. The upper hemisphere of the thermometric bulb, it will be seen, receives the radiant energy of the sun's rays which pass through the large central perforation; while the lower half of the bulb will be acted upon by the rays passing through the small perforations. These rays are reflected upwards by two inclined circular mirrors attached to the bottom of the exhausted chamber. It should be particularly observed that the areas of these inclined mirrors *together* should exceed the area of the great circle of the

bulb of the thermometer sufficiently to make good the loss of radiant energy caused by the imperfect reflection of the said mirrors, and also to make good the loss attending the passage of the solar rays through the crystal. A capacious water cistern, connected by flexible tubes with the external casing of the pyrheliometer, enables the operator to maintain the exhausted chamber at any desirable temperature. Engineers of great experience in the application of heat for the production of motive power and other purposes deny that the temperature of a body can be increased by the application of heat of a lower degree than that of the body whose temperature we desire to augment. The soundness of their reasoning is apparently incontrovertible, yet the temperature of the mercury in the instrument just described raised to 600° F. by means of the parabolic reflector, increases at once when solar heat is admitted through the circular apertures, although the sun's radiant intensity at the time may not reach one-tenth of the stated temperature. It should be mentioned that the trial of this new pyrheliometer has not been concluded, owing to very unfavorable atmospheric conditions since its completion. For our present purpose the great fact established by the illustrated instrument is sufficient, namely that the previous temperature of a body exposed to the sun's radiant heat is immaterial. The augmentation of temperature resulting from exposure to the sun, the pyrheliometer shows, depends upon the intensity of the sun's rays.

Regarding the temperature prevailing during the lunar night, its exact degree is not of vital importance in establishing the glacial hypothesis, since the periodical increment of temperature produced by solar radiation is only a fraction of the permanent loss attending the continuous radiation against space resulting from the absence of a lunar atmosphere; besides, all physicists admit that it is extremely low. Sir John Herschel says of the night temperature of the moon that it is "the keenest severity of frost, far exceeding that of our Polar winters." Proctor says: "A cold far exceeding the intensest ever produced in terrestrial experiments must exist over the whole of the unilluminated hemisphere." The author of "Outlines of Astronomy" has also shown that the temperature of space, against which the moon at all times radiates, is −151° C. (−239°.8 F.), Pouillet's estimate being −142° C. (−223°.6 F.). Adopting the latter degree, and allowing 81°.11 for the sun's radiant heat, we establish the fact that the temperature of the lunar surface presented to the sun will be 223°.6 less 81.°1, or −142°.5 F., when the earth is in aphelion. It will be well to bear in mind that when the earth is in the said position, the sun's rays acting on the moon subtend an angle of 31′ 32″, hence the loss of heat by radiation against space will be diminished only 0.000021 during sunshine. Nor should Herschel's investigation be lost sight of, showing that stellar heat bears the same proportion to solar heat as stellar light to solar light. Stellar heat being thus practically inappreciable, the temperature produced by stellar radiation cannot be far from absolute zero—an assumption in harmony with the views of those who have studied the subject of stellar radiation, and consequently regard Pouillet's and Herschel's estimate of the temperature of space as being much too high.

Having disposed of the question of temperature, let us return to the practical consideration of the glacial hypothesis. The formation of annular glaciers by the joint agency of water and the internal heat of a planetary body devoid of an atmosphere and subjected to extreme cold is readily explained on physical principles. Suppose a sheet of water, or pond, on the moon's surface, covering the same area as the plateau of Tycho, viz., 50 miles diameter and 1960 square miles. Suppose, also, that the internal heat of the moon is capable of maintaining a moderate steam pressure, say 2 lbs. to the square inch, at the surface of the water in the pond. The attraction of the lunar mass being only one-sixth of terrestrial attraction, while the moon's surface is freed from any atmospheric pressure, it will be evident that under the foregoing conditions a very powerful ebullition and rapid evaporation will take place, and that a dense column of vapor will rise to a considerable height above the boiling water. It will also be evident that the expansive force within this column at the surface of the water will be so powerful at the stated pressure that

the vapor will be forced beyond the confines of the pond in all directions with great velocity. No vertical current, it should be understood, will be produced, since the altitude of the column, after having adjusted itself to the pressure corresponding with the surface temperature of the water, remains stationary, excepting the movement consequent on condensation from above. The particles of vapor forced beyond the confines of the pond, on being exposed to the surrounding cold, caused by unobstructed radiation against space, will of course crystallise rapidly, and in the form of snow fall in equal quantity round the pond, and thereby build up an annular glacier. As the radius of the vaporous column exceeds 25 miles, it will be perceived that, notwithstanding the rapid outward movement, before referred to, some of the snow formed by the vapors rising from the boiling pond will fall into the same, to be melted and re-evaporated.

In connection with the foregoing explanation of the formation of annular glaciers, their exact circular form demands special consideration. An examination of Rutherford's large photograph of the lunar surface shows that, apart from the circular form of the walls, the bottoms of the depressions are in numerous cases smooth, rising slightly towards the center uniformly all round. The precision observable proves clearly the action of formative power of great magnitude. Referring to what has already been explained regarding the vaporous column of 25 miles radius, calculation shows that a surface temperature exerting the moderate pressure of 2 lbs. to the square inch will produce an amount of mechanical energy almost incalculable. Practical engineers are aware that the steam rising from a surface of water 10 square feet, heated by a very slow fire, is capable of producing an energy of 1 horse-power; consequently a single square mile of the boiling pond will develop 2,780,000 horse-power. This prodigious energy will obviously be exerted *horizontally*, as the weight of the superincumbent column of vapor balances its *expansive* force precisely as the weight of our atmosphere balances its expansive force. But unlike the earth's atmosphere, which is restrained from horizontal movement by its continuance round the globe, the vapor of the column of 50 miles diameter is free to move beyond the confines of the pond. A very powerful horizontal motion, especially of the lower part of the vaporous mass, will thus be promoted, acting in radial lines from the center, the principal resistance encountered being the friction against the water. Considering that the friction against the surface of the ocean, caused by the gentle trade-wind, is sufficient to produce the Gulf Stream, we need no figures to show the effect on the water in the boiling pond produced by the vaporous mass propelled by an energy of 2 lbs. to the square inch, in radial lines towards its confines. A circular tidal wave of extraordinary power, together with a return under-current towards the center, will obviously be the result. But agreeably to the laws supposed to govern vortex motion, these currents cannot be maintained in a radial direction. A rotary motion, rapidly augmenting, will take place, producing a vortex more powerful than any imagined by Descartes. The radial currents of the vaporous column having assumed a spiral course, will rapidly acquire a velocity exceeding that of a cyclone. The practical effect of the powerful movement of the vortex, it is reasonable to suppose, will resemble that of a gigantic carving-tool whose thorough efficiency in removing irregularities has been proved by the exact circular outline presented by thousands of lunar formations. The terraces within the "ring mountains" indicated on Beer and Mädler's chart, it may be shown, were produced by evaporation resulting from low temperature and reduced energy after the formation of the main glacier.

There is another feature in the lunar landscape scarcely less remarkable than its circular walls and depressions. In the center of nearly all of the latter one or more conical hills rise, in some cases several thousand feet high. Has the rotary motion of the boiling vortex any connection with these central cones? A brief explanation will show that the connection is quite intimate. The underrated estimate that 10 square feet of surface under the action of slow fire is capable of developing one horse-power proves the presence of a dynamic energy exceeding 5,000,000,000 of horse-power

at the base of the vaporous column resting on the boiling water of a pond as large as that of Tycho. No part of this power can be exerted vertically, as already explained, on the ground that the weight of the vapor restrains such movement. The great velocity of the vortex resulting from the expenditure of the stated amount of dynamic energy will of course produce corresponding centrifugal force; hence a maelström will be formed capable of draining the central part of the pond, leaving the same dry, unless the water be very deep, in which case the appearance of a dry bottom will be postponed until a certain quantity of water has been transferred to the glacier. It should be observed that the central part of the bottom, freed from water, will also be freed from the surrounding cold by the protection afforded by the vaporous mass. The quantity of snow formed above the center, at great altitude, will be small, and of course diverged during the fall. Evidently the dry central part, prevented, as shown, from cooling, will soon acquire a high temperature, admitting the formation of a vent for the expulsion of lava, called for as the moon, whose entire dry surface is radiating against space, shrinks rapidly under the forced refrigeration attending glacier-formation. Lava-cones similar to those of terrestrial volcanoes, and central to the circular walls, may thus be formed, the process being favored by the feebleness of the moon's attraction. The existence of warm springs on the protected central plains is very probable; hence the formation of cones of ice might take place during the last stages of glacier-formation, when those plains no longer receive adequate protection against cold.

In accordance with the views expressed in the monograph read before the American Academy of Science, continued research has confirmed my supposition that the water on the moon bears the same proportion to its mass as the water of the oceans to the terrestrial mass. I have consequently calculated the contents of the circular walls of the "ring mountains" measured and delineated by Beer and Mädler, and find that these walls contain 630,000 cubic miles. The opposite hemisphere of the moon being subjected to similar vicissitudes of heat and cold as the one presented to the earth, the contents of the circular walls not seen cannot vary very much from those recorded in "Der Mond"; hence the total will amount to 1,260,000 cubic miles. Allowing for the difference of specific gravity of ice, the stated amount represents 1,159,000 cubic miles of water. But "Der Mond" does not record any of the minor circular walls which, as shown by the large photograph before referred to, cover the entire surface of some parts of the moon. On careful comparison it will be found that the contents of the omitted circular formations is so great that an addition of 50 per cent. to the before-stated amount is called for. An addition of 25 per cent. for the ice-fields, whose extent is indicated by cracks and optical phenomena, is likewise proper. The sum total of water on the moon, therefore, amounts to 2,028,600 cubic miles.

Adopting Herschel's estimate of the moon's comparative mass, viz. 0.01 1364, and assuming that the oceans of the earth cover 130,000,000 square miles, it will be seen that the estimated quantity of water on the moon corresponds with a mean depth of 7.250 feet of the terrestrial oceans.* This depth agrees very nearly with the oceanic mean depth established by the soundings for the original Atlantic cable, viz. 7,500 feet; but the result of the Challenger Expedition points to a much greater depth. This circumstance is by no means conclusive against the supposition that the satellite and the primary are covered with water in relatively equal quantities. The correctness of Sir John Herschel's demonstration proving the original tendency of the water on the lunar surface to flow to the hemisphere furthest from the earth must be disproved before we reject the assumption that the quantity of water on the surface of the moon bears the same proportion to its mass as the quantity of water on the earth to the terrestrial mass.

* $\frac{2028600\times5280}{130000000\times0.01136^4}$=7,250 feet mean depth of terrestrial oceans corresponding with water on the moon.

MESSRS. P. AND W. M'LELLAN, of Glasgow, have obtained the contract to supply the steel work of ten bridges, four of which are to be 100 ft. span, and six 75 ft., for the Midland Railway of India.

# PERFORMANCE OF STEAM ENGINES.

By GEO. H. BARRUS.

Written for Van Nostrand's Engineering Magazine

My attention was some time ago called to the article in the February number of your magazine, written by Mr. John W. Hill on "Performance of Steam Engines" but I have not, until now, owing to pressure of business, had the opportunity which I wished to express my disapproval of the writer's conclusions. The subject is such an important one, and Mr. Hill's conclusions appear to be so erroneous and so liable to mislead those who are unfamiliar with steam engineering, and it may be also those even who are familiar with the subject, that I beg the liberty of criticising the article.

Mr. Hill states that he has made many experiments on first class engines, and has come to the conclusion that "for engines operating at piston speeds of 100 to 400 ft. per min. compounding will be found beneficial; but for high piston speeds of 600 or more feet, the single cylinder can be made to furnish the best economy," and he makes the proviso that "no benefit will be found in compounding for an engine working at six or less expansions." He seeks to exemplify these conclusions by quoting from the results of tests which he made on E. P. Allis & Co's compound engine at the Daisy Mill in Milwaukee, Wis., and a Harris-Corliss single cylinder engine of the common type, the location of which is not given, but which I understand is at the flour mill of A. A. Freeman & Co., La Crosse, Wis.

I have little to say in regard to Mr. Hill's conclusions, except to state that they do not appear to be sound. What I have to say refers to the propriety of basing such conclusions upon the results of the tests that are quoted.

I would call attention to the following table which gives the essential points in the data and results of the tests that bear upon the question :

| Kind of Engine. | Compound. | Simple. |
|---|---|---|
| Size of cylinder.....in. | 1 14×42<br>1 26×42 | 1 24×60 |
| Nominal power of eng. H.P. | 160. | 275. |
| Indicated horse power developed..... I.H.P. | 120.6 | 270.6 |
| Kind of Boilers Supplying Steam. | Babcock & Wilcox. | Horizontal Return Tubular, fitted with domes, and above the domes a steam drum. |
| 1. Proportion of stroke completed at cut-off..... | H P.Cyl. .198 | .156 |
| 2. Ratio of expansion by volumes..... | 23.4 | 5.5 |
| 3. Feed water consumed by engine per indicated horse power per hour (including entrained water in the steam).....lbs. | 17.22 | 18.58 |
| 4. Percentage of feed water which enters the engine in the form of entrained water.....per cent. | 6.3 | 13.0 |
| 5. Steam accounted for by indicators per I.H.P. per hour (not stated whether at cut-off or release but presumably at release).lbs. | 12.28 | 13.03 |
| 6. Proportion of feed water accounted for by indicators (including entrained water) | .713 | .701 |
| 7. Feed water consumed by engine per indicated horse power per hr. (not including entrained water...lbs. | 16.14 | 16.16 |
| 8. Proportion of quantity given in line 7 accounted for by indicators,..... | .761 | .807 |
| 9. Initial pressure in cylinder.....lbs. | 90.7 | 89.4 |
| 10. Revolutions per minute. | 76. | 59.6 |
| 11. Piston speed.ft. per min. | 532. | 596. |

1. It will be noticed, first, that the two engines are quite dissimilar in size. The cylinder of the simple engine is nearly as

large in diameter as the large cylinder of the compound engine. Just what sizes of cylinder should be used in making a thoroughly fair comparison is a matter which is open to question. But there is no question that the compound engine should be at least equal in power to the simple engine. Here the simple engine is some 70 per cent. greater in capacity. Second, it will be noticed that the compound engine was loaded far below its nominal capacity, while the simple engine carried practically its full load. Mr. Hill recognized the fact that the compound engine was unfavorably loaded in his statement that the load was too light for maximum economy, and an ineffectual effort was made to bring it up to the required point, by the use of a friction brake. He does not, however, appreciate fully the great loss induced by a light load in the case of compound engines, for he simply says that with a proper load, "the economy would have been quite as good."

These are two strong reasons why the results of the tests cannot be fairly compared to show the relative economy of compound and simple engines.

2. It will be seen that the compound engine was supplied with steam generated by water tube boilers with no steam drum (presumably), while the simple engine was supplied from fire tube boilers having not only a steam drum, but steam domes as well. It is frequently stated by advocates of fire tube boilers, that these two types of boiler produce steam of unlike degrees of dryness. Whether this is true or not, it seems to me that the prevalence of a feeling indicated by such statements would deter one from comparing engines that were supplied by these boilers. If this, however is not a sufficient objection to the comparison, the fact that unusual precautions were taken to secure dry steam, as was evidently done in the case of one of the plants, would seem to put a comparison altogether out of the question.

3. The results of the calorimeter tests as recorded bear me out in the claim that no fair comparison between the engines can be made, being supplied as they are with steam from two different boilers. The difference in the quality of the steam in the two cases is exceedingly marked. The Babcock & Wilcox boilers gave 6.3 per cent. of moisture, while the tubular boilers, in spite of the special arrangement of the plant which has been noted made with a view to produce dry steam, gave 13 per cent. of moisture! In passing, let me here encourage the advocates of water tube boilers to pursue their efforts. If there were no prospect before of their getting dry steam there is now good grounds for the hope that some day they may realize their expectations. In spite of domes and steam drums, it seems that the shell boiler still gives steam which is one-eighth water, while the water tube boiler has got the figure down to 6.3 per cent. With these facts staring at him, Mr. Hill will surely become the champion of water-tube boilers! Until these figures came to notice, I had supposed that engine economy and dry steam went hand in hand, but it seems that an engine can be supplied with steam containing as much as 13 per cent. of moisture, and still be the most economical engine on record!

4. Looking at the matter seriously, and taking the figures as they stand, it is altogether unreasonable to compare the performance of two engines, the steam for one of which contains 6.7 per cent. more moisture than the steam for the other. It is not fair to make such a comparison, even though the so-called "entrained water" is deducted from the gross amount used. I have experimental data which point to the probability that the presence of moisture in the steam leads to the formation in the cylinder of a much larger quantity of cylinder condensation, than would otherwise occur. The waste due to wet steam does not stop at the throttle valve, but follows through the cylinder and continually increases during its passage. If this had been taken into account by Mr. Hill, the comparison which he has made would result even more favorably to the simple engine than his figures have made it appear.

5. The reasons thus far given are quite sufficient to show that the tests are of no use whatever for making a fair comparison of simple and compound engines, but there is a still stronger reason not yet named.

Mr. Hill bases his figures of comparison on the amounts of feed water consumed by the engines, not including

the "entrained water" in the steam. The amount of entrained water is determined in each case by calorimetric tests. He really bases the comparison, then, on the indications which the calorimeter reveals of the state of humidity of the steam. I have no knowledge either of the type of calorimeter used, or of the method of conducting the trials. I have some knowledge however, of the general subject of calorimetric tests, a sufficient amount, at least, to be thoroughly aware of the delicate nature of those tests, if conducted with proper apparatus, and with sufficient care to insure reliable results. Although having no knowledge of these particular tests, I venture the assertion that they are wholly erroneous. The results of the engine tests, on the face of them, bespeak their inaccuracy. The reasons for this assertion are as follows: First the largest amount of moisture which I have ever obtained by calorimetric test of any boiler whatever, whether fire tube or water tube, is 3 per cent. Second, the largest proportion of feed water accounted for by the indicator that I have obtained from simple engines running under the conditions of the one tested by Mr. Hill, is 0.73, even in cases where the calorimetric test showed but 1 per cent. of moisture and the valves and piston of the engine were tight. I do not wish to be understood that I think it impossible for steam to contain so much moisture as the amounts given in Mr. Hill's article, but I do think it is impossible for a Corliss engine to develop an indicated horse power with a consumption of 18.58 lbs. of steam per hour, when that steam contains 13 per cent. of moisture, as was purported to have been done in the case in question.

If Mr. Hill has no stronger fabric out of which to frame a theory of the relative economy of simple and compound engines than that furnished by the examples given in his article, his opinion is not based on that careful attention to the matter which the importance of the subject and a due consideration of its merits demand.

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# THE LIMIT OF SPEED IN OCEAN TRAVEL.

By F. M. F. CAZIN.

Written for Van Nostrand's Engineering Magazine.

Prof. R. H. Thurston's article on the limit of speed in ocean travel, reproduced in the June issue of this journal, serves as an occasion for the publication of this polemical essay, but it is not the original cause thereof. I admit that, in assailing the views, as Prof. Thurston has expressed them, I assail all present and traditional teaching concerning the dynamical relations between the immersed solid and the immerging or submerging medium. I realize that I should plead for indulgence in so doing. I therefore do first state that in so bold a challenge I consider it to be fortunate to meet an adversary on the field of scientific strife of so high standing and well-deserved renown as Prof. R. H. Thurston.

In dynamics those learned in the matter have acquiesced in a case of precedents, while it so happened that the case to which the precedent has been habitually and traditionally applied is not analogous to the precedent.

Not Weissbach and Rankine alone, but all their preceding and succeeding writers on mechanics and dynamics have laid the foundation for their teaching concerning the dynamical relations now under consideration by stating the experimental and theoretical results obtained, when a jet of water projected from an orifice strikes a resisting solid face. The formula for the effect thus obtained as $S=\frac{v^2}{2g}$ has had a general universal and exclusive effect on all the teachings referred to.

At another place and at an earlier date, when discussing in publication this point of inapplicability with an equally learned adversary, I believe to have properly shown such to exist. It may, at this place, suffice to state that the value $g$

is inapplicable in the premises, both solid and medium being subject to gravitation absolutely and in common, and not the one as against the other.

But it is not this negative side of the question which it is proposed to discuss at present. It is at present my intention to be positive in showing that the questions, which Professor Thurston says admit of no definite answer, do indeed admit of such definite answer. But I also desire to precisely state, that unless the present teaching in dynamics, which I consider as a conglomerate of error and truth, caused by connecting cases not bound in analogism—be abandoned—such desirable definite answer cannot be made.

While in order to find the answer desired I have to find a new road of my own, I should not neglect to also show, that not only are more definite answers to be given, but that even those answers, definitely given by Prof. Thurston, suffer under the influence of the erroneous, incomplete and confused present teachings in dynamics, and are incorrect in consequence, and neither more nor less than popular fallacies.

In Prof. Thurston's essay there occur the following propositions, which I provide with numbers for the sake of reference, and with signs for values for the sake of more easy repetition.

(1) The resistance of a steamship or other vessel (=R) consists of two principal points:

(*a*) "The effort required to overcome the friction (=F) of the water on its wetted surfaces.

(*b*) "The force expended in producing the waves (=U) that are seen arising about every ship in motion.*

And the same author further states:

(2) "The friction of hull (=F) is found to be very nearly proportional to the area of wetted surface (=S$f$).

(3) "The nearer the form of the ship approaches that of a hemisphere the less must be the resistance due to friction, and between the latter shape and that elongated . . . form which gives minimum *head resistance* there must be some intermediate form which will give the least total resistance.

(4) "The power (=P) demanded to propel any vessel at ordinary speed varies as the square of her length (=$d^2$) nearly, or as the area of the transverse major section (=MS) and as the cube of the speed ($v^3$).

(5) "Two vessels being of equal speed ($v$) and similar form, but the one of twice the length (=$d$) of the other, the second will require four times the power of the first. The second vessel, however, carries eight times as much weight, and the power per ton of vessel is one half as much as would be demanded by the first, if driven at the higher speed.

(6) "For vessels loaded to a limit with machinery, the higher the speed demanded the larger must be the ship."

When dealing with mechanical problems all expressions used in any statement made must be assumed to have only one plain meaning; this is the one meaning as apparent from the common usage of words, and it is not to be tolerated that in writings on such problems or subjects ambiguity cover up a lack of full understanding. Nor is it admissible that interpretation, becoming possible only consequent to ambiguity of expression, be considered as genuine.

I shall therefore not undertake to find more in the propositions as stated, but what is evident and plain on their face without searching for more therein but what they evidently intended. But distinction must be made between ambiguity on the one side and a well defined new use of and for words on the other.

When expressing new ideas we find a necessity for using new words or for imparting to old words a new meaning.

So I shall have to introduce a new combination of words as: "Transverse average section." I further find the necessity for introducing a new distinction as between the value representing the

* Official Publications of the Royal School of Naval Architecture and Marine Engineering (1873, page 92 of *Annual*) substitute this "*force expended in producing waves*," by "*direct head resistance*," and then divide this resistance up into such caused by viscosity of water and such caused by the production of waves. The total treatment vividly reminds us of Goethe's Mephistophelic expression: Wo die Begriffe fehlen, Stellt stets zur rechten Zeit ein Wort sich ein.

volume and substance displaced by initial immersion (or submersion) and the value representing the volume and substance of liquid (or fluid) medium displaced by relative motion of solid and medium.

The substance displaced by the immersion of ship bottom equal in weight to the ship's total weight is the value which causes its buoyancy, and I therefore propose to express this value by "Buoyance" (=B), while I propose to properly henceforth use the expression "Displacement" (=D) for a total volume displaced of the medium by the solid in relative motion, it being immaterial whether the one or other be in stability as a total relative to third objects.

With the assistance of this new terminology I may proceed to the revision of Mr. Thurston's propositions.

Mr. Thurston's proposition may be correctly rendered by

(1) $$R = F + U.$$

(2) $$F = Sf$$

(4 & 5) $$P^{(1)} : P^{(11)} = d^{(1)2} : d^{(11)2} = MS^{(1)} : MS^{(11)} = v^{(1)3} : v^{(11)3}.$$

To express in mathematical values his propositions (3) and (6) I have attempted in vain on account of the ambiguity. It is for this reason alone that they cannot be considered as precise or correct, others not being considered.

In the first proposition again the value U is so loosely taken, is so absolutely indefinable that it almost excludes itself from discussion. The production of waves (=U) is evidently an effect of relative motion not conditional thereto. Waves are evidence for a waste of power and not a method for applying power or for its useful application. They are certainly not the effect by which to measure the resistance. If thus I am under necessity to treat part of the propositions as invulnerable, because they are of too misty a nature to admit of handling at all, I find enough in what is left to prove the incorrectness of what answers Prof. Thurston gave to his own question, and definite answers where he thinks the questions admit of none.

Coulomb, Rennie and Morin established the since then acknowledged facts that

(*a*) Friction rates as the weight of one substance effective on the other.

(*b*) With smooth faces friction does not increase at the ratio of surfaces being in contact.

(*c*) Friction does not rate with velocity.

The fact (*b*), discussed and admitted since 1833 by the French Academy of Science, makes Prof. Thurston's proposition (2) appear as a fallacy.

(3) In the case of ocean going vessels, friction rates with their weight and not with their surface, it rates with the values B and D, and is therefore no independent coefficient, no factor in the premises at all. But when admitted parallel with and as an effect of weight it becomes for smooth faces only an insignificant coefficient,* when compared with the sole one by which indeed the resistance to relative motion can be valuated. Beaufoy found the cohesive action on wetted smooth solid surfaces to act as an increase of the effect of weight in relative motion to amount to 0.32 kg. per square meter.

Proceeding to Prof. Thurston's third proposition, I find that he establishes the hemisphere as a standard form for comparing others therewith, or to serve as the first form of B to be considered. I beg leave to more closely accommodate to mathematical precedent in selecting the cube $=1^3$ as standard form for comparison, because our arithmetical and stereometrical system admits of no other, all values relating thereto and not to the sphere. As first power for this cube I then select the sole dimension for length used, also by Prof. Thurston, assuming that it be his intention, though not stated, to exclusively speak of effective length or of the length on the waterline, for which length I have selected the expression $=d$.

The form of vessel first referred to in

* How long time it takes for new results in scientific research to reach even those most interested in these results is well illustrated in the matter of friction. The *Annual* of the Royal School of Naval Architecture and Marine Engineering for 1873, in an article "Comparative *Resistances* of Ships, etc.," has the following:

The resistance opposing the motion of any vessel is of two kinds—surface friction, and *what is commonly called direct head resistance*. The same article states as experimental result; "the resistance from friction is less per foot of length for a long surface than for a short one." With all this the results of scientific research on the subject made by the three French scientists forty years earlier, were then unknown at the English Royal Naval School, as they at present were to Prof. Thurston.

proposition (3) can as to its volume then be correctly expressed by:

$$B = d^3 \times \frac{\pi}{6} \times \tfrac{1}{2}.$$

I then may be permitted to generalize the value $\frac{\pi}{6} \times \frac{1}{2}$, so as to render it applicable to all cases and to all forms of vessels, or to all values for B, and to do so by calling this value the *ratio of the volume of the immersed part of vessel to the cube of its length* (=R.*o*.V.) Then I have a general valuation for all vessels without exception in

$$B = d^3 \times \text{R.}o\text{.V.}$$

Or, we may express this same value in a more plastic manner and method by writing it as

$$B = d^2 \times (d \times \text{R.}o\text{.V.})$$

This applied again to the hemisphere [compare proposition (3)] would read:

$$B = d^2 \times \frac{0.5236}{2} d.$$

When comparing the spherical form with other forms $d^2$ constitutes the transverse section and $\frac{0.5236}{2} d$, the length of a body being in volume an equivalent of the hemisphere, or $\frac{0.5236}{2}$ represents a coefficient to the section $d^2$, the two representing the value as "*Transverse average section*" of an equal volume of uniform transverse section having $d$ as length.

Having thus prepared a basis for comparison of different forms for the same volume, I may proceed to test propositions (3 and 4) on their merit. Proposition (3) speaks of the *resistance* to motion (=R), proposition (4) of the power demanded to propel (=P). As the power to propel required (=P) does not depend on qualities of the vessel alone, but depends also on the modus of applying such power as against the resisting medium, and further on the qualities and conditions of the resisting medium, it is absolutely impossible to measure the value P by the qualities of the vessel alone, as Prof. Thurston attempts it in his fourth proposition. But the *resistance* to motion (=R) of vessels of all shapes, in all relative positions and at all velocities imaginable may be measured, rated and compared by qualities exclusively of these vessels themselves.

Therefore, when Prof. Thurston rates the value P exclusively on qualities of the vessel he commits an error. But if we were to substitute the value for resistance (R) for the value for "propelling power required" P, even then would proposition (4) not hold good, which, expressed in typical values, would read:

$$P \text{ or } R = d^2 = MS.$$

Now MS, in the case referred to, is as

$$MS = \frac{\pi}{4} \times \tfrac{1}{2} = 0.3927$$

and $d^2 = 2$

As true it is, that $2 > 0.3927$,

as true it is that the propelling power canot be measured by the square of the vessel's length, and also by the area of her transverse major section.

Knowing already either one or the other of Mr. Thurston's propositions (4) to be false, it may further be shown, that both are fallacies, even when reducing the value P to the value R as exclusively rational in the premises.

And it may also be proven that

$$R = d^2 \times \text{R.}o\text{.V.}$$

be correct for all cases of motion of immersed or submerged solids relative to fluids (water, air), and for bodies (vessels) of all forms and under all variations of relative position of the given form to the direction of motion, as long as it be properly understood:

(*a*) That $d$ is in all cases the length (axis) in the direction of relative motion.

(*b*) That such part of the fluid as remains comparatively stationary with the solid as a consequence of the form of the solid and of the cohesion proper of the fluid, must be considered in all dynamical relations as a supplementary volume to that of the solid.

To express the proposition

$$R = d^2 \times \text{R.}o\text{.V.}$$

in words, the reading would be as follows:

"The resistance offered by an immersed (or submerged) solid (vessel) to relative motion as against the liquid (or fluid) (immersing or submerging) varies for all forms and relative positions as the *transverse average section*, or as the section of an ideal solid, to which the length of

the given solid *in the direction of relative motion* is the length ($=d$), the ideal solid having a uniform transverse section, and the volume of both being equal."

"And such resistance is neither represented by the transverse major section nor by the square of the solid's constructive length."

I may then be permitted to render proof for such thesis.

As I undertake to overthrow traditional and so far uncontradicted propositions in dynamics, there is a resulting necessity to return to the most elementary class of proof for what new thesis I propose. I therefore may be pardoned for the use of such elementary method.

Only by returning to the very simplest of given conditions is it possible to overthrow errors, set up by time and tradition as invulnerable dicta, having assumed almost the general acknowledgment as if they were axioms.

I propose to make use of a burette having a transverse section and bottom $=1^2$, and to fill it with water of a density $=1$ to an elevation of $10-0.5236$. And I propose to use a solid sphere with a diameter$=1$ and a consequent volume

$$=1^3\times\frac{\pi}{6}=0.5236.$$

and also of a density$=1$.

Carefully avoiding all effect of fall, as foreign to the problem underhand, which concerns only the measurement of displaced volumes, I immerse the described sphere in the described column of water.

From the conditions, as stated, it will then be found to have resulted, that the buoyancy of the sphere is attained at the point of its total immersion. But its total immersion will occur at a point 0.5236 higher than the elevation at which the column of water stood previous to the immersion. And the elevation of the total column of water and sphere therein submersed will be

$$=10-0.5236+0.5236=10.$$

And the upper $1^3$ of the column will then consist of $1^3\times 0.5236$ solid $+\ 1^3\times 0.4764$ liquid.

It is on the basis of the conditions as thus given that I shall consider the further effect of relative motion of solid and liquid.

Be it assumed that the solid sphere after being fully immersed shall descend in this column of a uniform transverse section $=1^2$, and of an elevation$=10$ for a distance$=1$, equal to its own diameter (in this case$=d$, or as the length in the direction of motion). While at the start of this later motion and under an assumed elevation of 10, the upper $1^3$ consisted of $1^3\times 0.5236$ solid$+0.4764$ liquid, and the 2d $1^3$ thus consisted exclusively of liquid in volume as $1^3$, subsequent to the fall for a distance$=1$, the upper or 1st $1^3$ will consist of all liquid, an addition thereto having been made for$+0.5236$ of liquid, which same portion has been raised from the 2d $1^3$ to the 1st $1^3$. Expressed in words this fact would be read:

"By a fall in submersion for the distance of its own length measured in the direction of motion, a solid raises a volume of the liquid equal to its own volume for the distance of its own length measured in the direction of fall."

Would I use in place of the burette a horizontal trough measuring $1^2\times 10$, and filled with water in volume equal to $(1^2\times 10)-0.5236$, and immerse therein the sphere of a diameter$=1$, thus filling the trough, and if then I would move the sphere horizontally the effect would then be a horizontal displacement of the same character and value in place of a vertical displacement in the previous case.

And then the result may be expressed by:

"The motion of a solid in immersion for once its own length, measured in the direction of relative motion displaces a volume of the liquid being equal to the solid's own volume."

For want of space I must desist from further demonstration of the absolute and general correctness of this proposition, but must leave it to critical readers to ascertain the fact for themselves. The proposition is true for all dynamical relations as between solids immersed and immersing fluid.

I shall draw attention only to one useful conclusion to be drawn from this proposition amongst many it will permit, one relating immediately to the subject under hand. And the conclusion thus drawn represents a definite answer in itself to one of the questions, according to Prof. Thurston, admitting of none.

An ocean steamer measuring on the water line a length=800 feet=$\frac{800}{3.28}$ =243.9 meters weighing and displacing in initial immersion 38,000 tons, or per meter of immersed length $\frac{38,000}{243.9}$=155.8 tons, does move from its front to its keel per meter of travel 155.8 tons of water.

If such steamer shall travel 2,000 meters, with a speed of about a nautical mile in every three minutes, or twenty miles an hour, then its pumping capacity should be $\frac{2000}{3}\times 158.8$ tons = 103.866⅔ tons or cubic meters of water per minute, when no power is wasted in creating waves. And the horizontal column of water having the length of travel to be moved for the distance of the immersed length of the ship will have a uniform transverse section=155.8 square meters.

The raising of this quantity of water for 1 foot in one minute would demand 6.295 theoretical horse-power. If the assumption of Prof. Thurston be correct, that such a ship would require for the production of approximating such speed 35,000 horse-power, then the horizontal removal from front to stern for a distance of 800' must be equivalent to the raising thereof $\frac{35,000}{6.295}$=5.56 feet high, which it need not be under proper method for removal on the proper line of motion.

Having thus demonstrated the labor performable by each steamer under given conditions, I may proceed to answer the question of shape in as definite a manner.

In my elementary experiment I have demonstrated with a shape of volume having, as ships have a non-uniform transverse section, or with a transverse major section of $=\frac{\pi}{4}$.

But a cylinder of equal length=$d$=1 having a uniform transverse section AS=$\frac{\pi}{6}$, being in this as in all cases by volume=$d^3\times$R.$o$.V. as AS=$d^2\times$R.$o$.V.=$1^2\times 1\,\frac{\pi}{6}$ possesses an equal volume with the sphere considered, $d$ being=1 for both.

But AS : MS=2 : 3.

If these two different forms for the same volume are treated as I have treated the sphere all the effects of motion and displacement obtainable and perceptible from the remaining result are identical. The transverse average section is in common to both, the major section being only a quality for one, which has in no wise influenced the remaining result of displacement. And with the remaining observable result of effective displacement alone I am dealing at present.

What is called head resistance is indeed no more than the increase of volume of moving solid by shape causing part of the medium to also move with and as if a supplementary part of the solid volume, and may be treated as a special matter, when first the influence of volume be properly understood, and of shape in general for equal volumes. The effect being the same the resistance such as classified must be the same, and thus not the transverse major but average section is conditional to the measurement of resistance, and such resistance is in consequence properly expressed by

$$R=d^2\times R.o.V.$$

The effect of the indicated motion of the sphere is undeniably uniform, and not intermittent for all motion at uniform velocity. The displacement for the length of motion=$v$ is in consequence the same as such by a body of equal length=1 having a uniform transverse section. And this uniform transverse section is in all possible cases=$d^2\times$R.$o$.V.

Thus the permanent, lasting constant effect of relative motion of submerged solid and submerging liquid is properly expressed as $R=d^2\times R.o.V.$

The next step to be taken in my elementary demonstration will be to consider the effects of motion and displacement by equal volumes with different axes in the direction of motion. I therefore make also use of a parallelopiped

$$B=1^3\times\frac{\pi}{6}=1^2\times\frac{\pi}{6}\,1=0.5236.$$

And I propose to consider the motion in submersion of this parallelopiped once in the direction of its axis $d'=\frac{\pi}{6}$, and another time in the direction of its axis $d''=1$. When moving on its short axis

$=d^{1}=\frac{\pi}{6}$ a total volume $=D^{(1)}$ is displaced within a moving distance $=V^{(1)}=\frac{\pi}{6}=d^{1}$.

When moving on its long axis $d^{11}=1$, a total volume $D^{(11)}=\frac{\pi}{6}$ is displaced only within a moving distance $V^{(11)}=1$, but in moving only a distance $V^{1}=\frac{\pi}{6}$ the resulting displacement $D^{111}$ from motion on the axis $d=1$ would only be

$$D^{111}=\frac{\pi}{6}\times\frac{\pi}{6}=\frac{\pi^2}{6^2},$$

and therefore

$$D^{1}:D^{111}=R^{1}:R^{111}=\frac{\pi}{6}:\frac{\pi^2}{6^2}=1:\frac{\pi}{6}$$

By $R=d^2\times R.o.V.$

we have $R^{1}=\frac{\pi^2}{6^2}\times\frac{6^2}{\pi^2}=1,$

and $R^{111}=1^2\times\frac{\pi}{6}=\frac{\pi}{6}$

and $R^{1}:R^{111}=1:\frac{\pi}{6}$

or at the precise inverse rate of their submerged length measured in the direction of motion.

The result of this experiment, the full and further testing of which must also be left to critical readers, then would be applicable on ships and ocean travel in the following form:

"The resistance to two ships in motion both having the same amount of volume submerged, but being of different length, rates for one and the other at the inverse ratio of their (submerged) length measured in the direction of their motion, the shorter one, with same volume finding the greater resistance (under equal velocity), and a resistance increased *at the the same rate* as its (submerged) length in the direction of motion is shorter than that of the vessel of same submerged volume with which it is compared."

As early as November, 1881, I directed attention by publication to the fact, that a correct rating for resistance of ships for insurance purposes, for speed measurement, and for nautical construction may be obtained from this formula, (Comp. F. & M. Rd., Nov., '81.)

If in the light of these results we subject Mr. Thurston's proposition (3) to a critical test, we may establish the relative resistance $(=R^{(a)})$ of a hemisphere to motion by $R=d^2\times R.o.V.$ as $R^{(a)}=1^2\times\frac{\pi}{6\times 2}$, as often as the diameter 1 is in the direction of motion. A cylinder of a transverse section $=\frac{\pi}{12}=0.2618$ with a length $d=1$ would produce the absolutely identical effect in displacement with equal velocity.

Which, then, is the elongated form "*which gives the minimum head resistance*," referred to by Mr. Thurston as *non-plus ultra*, as between which and the hemisphere the practicable achievement must remain intermediate?

The displacement theory can give answer also to this query.

By building a vessel of the same submerged volume $R=\frac{\pi}{12}$ in the shape of two half cones of an elevation $=1$ with bases joined, the result will be a length $d=2$ and

$$\text{by volume}=2^3\times R.o.V.=\frac{\pi}{12},$$

and by $$R.o.V.=\frac{\pi}{8\times 12},$$

and $$R=2^2\times\frac{\pi}{8\times 12}=\frac{\pi}{24}.$$

Or, again, by doubling the length for the same volume the resistance is reduced to one half.

Therefore, there is good reason for lengthening the axis in the direction of motion, and good reason for facing motion with a sharp angle in order not to increase the moving volume, because real head resistance is the cause of moving a part of the liquid, as if it were a part of the solid.

It is sufficient to know that the essential conditions by which the resistance of a vessel to motion must be rated is its submerged volume as a consequence of its weight, and that the main quality lessening resistance thereof is the distribution of such given volume and weight over as great a length and as small a transverse average section as possible.

Proceeding then from the valuation of resistance $(=R)$ to valuating propelling

power required (=P), it follows from the facts, as shown, namely, that resistance does *not rate* as $d^2$ the square of length, and does not rate as MS, the transverse major section, that neither P the propelling power can thus rate.

The propelling question, or the question of overcoming such resistance to motion, demands

(*a*) The production of the highest mechanical power by the least weight of machinery and coal.

(*b*) The application of such power in the most effective method against the medium offering both the resistance to motion and to the propelling power applied.

All endeavors of late years have exclusively been in the direction of the point *a*. Since the substitution of the screw for the paddle-wheel no progress has been made in the direction of the point *b*, but as the world is ready for one step more, it will inevitably be made, and I would be much pleased if nautical constructors would deign to take the hint and try the pump once more, but this time taking the water from the ship's front and ejecting it sternward in a straight line in absolute conformity with the intended motion, taking the precaution to take up the water in a narrow vertical line at the head, and to eject sternward on as broad a face as practicable so as to lessen the resistance in the direction of motion, and to increase it where it is contributive to motion. In the method of jet propeller, hitherto exclusively tried, the inlets and outlets were in absolute conflict with the teachings of my new displacement theory.

"The ship of the next century" need not be, as Prof. Thurston forestalls it, a naval Babylonian tower, but it will be one of rational dimensions, being in harmony with such dimensions as the human race can properly master and control; but "*the ship of the next century*" will first apply its motive power in a more rational method than the propeller screw represents. The crank-shaft will be done away with. The water, to be moved from head to stern in order to produce relative motion, will be conducted not on a circuit around the good ship's body, but right through it lengthwise in a straight line, and the water rejected at the stern will steer the vessel. And the propelling power will be applied to the screw at its circumference, in place of its center if a screw be used at all. And in consequence the weight of machinery for exercising the same propelling power will be materially less. And the resistance of the water at the stern being increased, and the resistance at the head being lessened, the same amount of power will produce greater speed. Thus, not a "Leviathan" representing increased dimensions, but an "Investigator" representing the progress of human thought, will be "the ship of the next century."

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## THERMO-ELECTRICITY.

From "The Electrician."

Although many combinations of conductors producing a greater or less E.M.F. under the influence of heat have already been described, the search for bodies which possess this property has acquired a great interest on account of their possible application to thermo-electric generators. M. G. Chaperon has, according to the *Revue Industrielle*, methodically studied from this point of view a certain number of chemical compounds, chiefly chosen amongst those which can be easily reproduced in their active state. The method employed in this research is characterised by being applicable to fragments of any form whatever, and, if need be, of very small dimensions. It consists in applying two points of one of these fragments to two metallic walls, which conduct heat well, whose temperatures are evaluated as closely as possibly, and which serve as electrodes to show and measure the E.M.F. of the couple thus formed. One of these walls is that of a thin silver tube traversed by a current of water at the temperature of the surrounding air, and forming part of a pair of pincers with which the body under consideration is held. By means of these pincers a second point of the body is ap-

plied against a hot wall, that of an iron crucible full of fusible alloy, and into which a thermometer is plunged. Contact ought to be insured by a constant pressure. The procedure is then to measure during slow variations of temperature a series of values of the difference of potential of the two plates. The iron crucible is united to the electrical measuring apparatus by a silver wire sufficiently long for its extremity to remain cold. The E.M.F. measured is then, in virtue of the law of successive contacts, that of the couple formed by the body which is under investigation and silver. For certain compounds capable of attacking iron a thin leaf of silver is also interposed at their point of contact with the crucible. For more elevated temperatures another arrangement has also been employed, in which the hot contact is taken at a point of a silvered copper bar heated at one extremity. The temperature is evaluated at another point of the same section of this bar with a second body already studied, and which thus serves as thermometer. In the various couples thus formed the contacts of active substances with the electrodes ought to take place by small surfaces, which are as distant from one another as possible, in order that the temperatures of these contacts may be as nearly as possible those of the electrodes, which alone can be estimated. One thus obtains with substances in general bad conductors elements of an enormous resistance; therefore the rapid measurement of the E.M.F.'s is only rendered practically possible by the use of Lippmann's electrometer. Besides, this only serves to show the equilibrium of the force measured with that given by a potentiometer with wire of a reduced form giving $\frac{1}{500}$th of a volt. It is possible with this conjoint apparatus to obtain sufficiently easily curves representing the law of variation of the E.M.F.'s as functions of the fall of temperature. M G. Chaperon then quotes some examples of measures thus made on substances little studied and enumerated below. Positive bodies: iodide of silver, phosphide of zinc, sulphide of tin, crystallised galena, oxide of copper in a very thin plate, arsenide of zinc. Negative bodies; sulphide of silver specular iron, crystallised galena. The curves representing the force as a function of the fall of temperature indicate in general a uniform increase starting from a certain point; they have been followed up to 250 or 300 degrees. Nevertheless, for the iodide, and, above all, for the sulphide of silver, the law of variation undergoes a sudden change, and hardly appears susceptible of being represented by a continuous function.

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# STRENGTH OF OBLIQUE ARCHES.

By JOHN L. CULLEY.

Written for Van Nostrand's Magazine.

## Chapter VIII.

90. The static problems in masonry arches is to so construct, or so arrange the material composing the arch, that the line of pressure resultant from the weight and load of the arch shall pass through it in planes parallel with the arch faces, to the end that the arch stress shall be uniform throughout the length of the arch, and that the courses shall be relieved, as far as possible, of the tendency to move or slide over one another.

91. Without discussing the problems involved, we will suppose that the bond of the arch is ample to resist all ordinary external forces acting upon the arch, and that the arches now to be considered are so constructed that the line of pressure falls within the middle third of the thickness of the arch, and that it is located on the center line of the depth of the arch, as for instance on the middle line $a\ a$, Fig. 41.

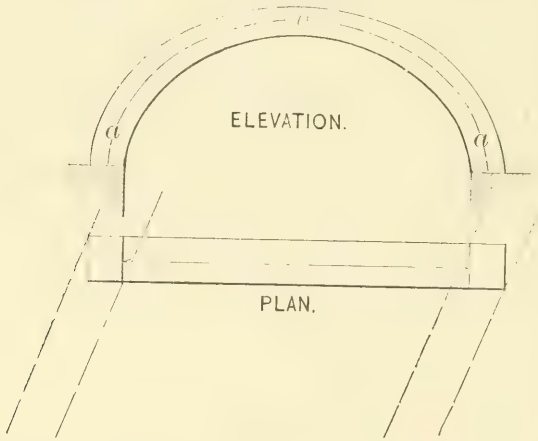
92. Undoubtedly the disposition of the material composing the arch has much to do in determining the direction of the line of pressures.

In a right arch the coursing beds being parallel with the spring lines or axis of

the arch, the line of pressure passes directly to the abutments in lines normal to those beds, and therefore in planes parallel to the arch faces. We have seen (article 24 and Fig. 11) that in an oblique arch with straight beds, there was a tendency for the arch stress to pass to the abutments in lines normal to such straight beds, and it would undoubtedly do so were it not for the distorted strains in the overhanging oblique ends of the arch.

Let Fig. 41 be an elliptical arch. With straight radial beds it is evident that the line of pressure will be parallel with the arch faces, and this is true if the arch is a single narrow rib. Now, an oblique arch may be regarded as composed of a

Fig. 41




number of elliptical ribs arranged as in Fig. 40. These ribs may be so narrow, that they will not break the continuity of the arch cylindrical intrados. The line of pressure in any single rib will be parallel to the arch face, and therefore the line of pressure for the whole arch must also be parallel with the arch face. The line of pressure would not be altered in this respect if the several ribs were reduced to the exact cylindrical intrados of the arch.

93. Again, in a helicoidal arch there is always a point on either side of the crown, where the coursing beds are normal to the arch face.

Now, if the arch be limited by imposts or abutments at these normal beds, the line of pressure will evidently pass through the arch normal to the impost and in lines parallel with the arch face, the same as in a right segmental arch, provided that no bed between the imposts shall depart from the normal to the arch face, equal to the angle of friction. It will be shown directly that this departure, for arches of the least practicable obliquity never amounts to as much as one-half of the angle of friction. If the abutment be lowered below the normal beds the line of pressure will continue parallel to the arch face until a bed is reached whose departure from the normal to the arch face equals the angle of friction. Even then if the surfaces of this lower bed and those below it resist the tendency to move, the line of pressure will continue parallel with the arch face.

94. We conclude therefore that the line of pressure is parallel to the arch faces when the condition of greatest stability in an oblique arch is to be realized, and that it should be regarded as parallel to the arch faces in discussing the strength of oblique arch.

95. Perfect stability is realized when the coursing beds are exactly normal to the line of pressure. In the logarithmic method the generating line in the coursing beds is exactly normal to the arch face, and, therefore, practically complies with this condition of perfect stability, and needs no further discussion in this particular.

96. Let S X G, Fig. 42, be the end de-

velopment of the arch for the middle line on the arch face between the intrados and the extrados. S X G will also represent the direction of the line of pressure, since it is parallel with the arch face. Draw the straight line S X G, joining the extremities of the development, and draw

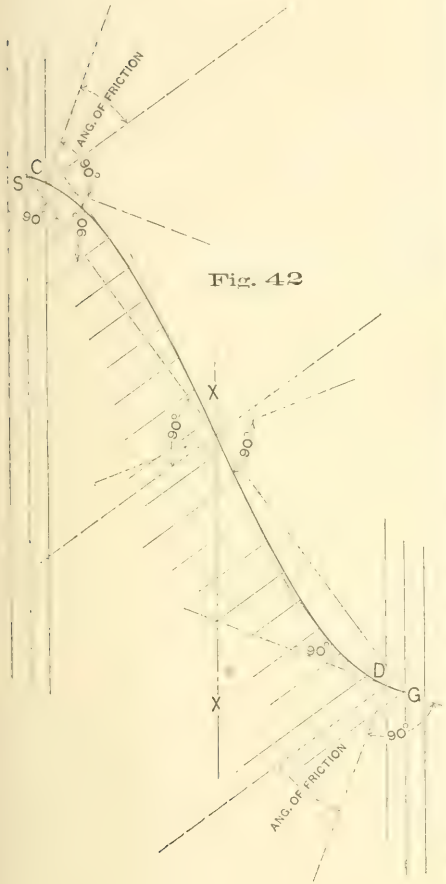



Fig. 42

the middle line of the coursing beds normal to this line, as heretofore described. At A and B these lines will be normal also to the line of pressure. X, the middle of the end development, is the point between A and B, of the greatest departure of the middle line of a coursing bed from the normal to the line of pressure. For an oblique arch of 25° obliquity this departure is only 12°, the arch, therefore, is for all practical cases perfectly safe between A and B. At C and D the middle course lines depart from the normal to the line of pressure equal to the angle of friction. And the courses below these points will slide over one another if not otherwise resisted. Between C and S the tendency will be for the courses to move over one another into the arch, and between B and G to move out from the arch. It will not be safe to construct the arch below D, unless precautions be taken to thoroughly resist the outward tendency of the courses between D and G. In an oblique arch of 25° obliquity the point D is 10° above the horizontal on the full semi-circular right section, the angle of friction being taken as 36°. The stability of oblique arches proves that the angle of friction for the courses of the arch must far exceed 36°, especially so for well cemented masonry. The arch of 25° obliquity would unquestionably be safe for 160° on the right section. At 40° above the horizontal the coursing beds in this arch would be normal to the arch face. If the arch below 10° was resisted by the wing walls, or if the courses were doweled to prevent slipping the whole arch could be made stable for a full semicircle on the right section. Such construction is not recommended. Segmental arches are far preferable. It is true, however, that full semi-circular helicoidal arches of slight obliquity have been built, that have given the most satisfactory results.

It should be noted the sliding tendency of the courses immediately back in the arch from its face between D and G, is opposed by the abutment of the arch, and therefore cannot move without disturbing the abutment.

That the courses in the arch face below D do not, in carefully constructed oblique arches, move the least outward, is accounted for by the fact that they are held tight in the arch by the weight of the spandrel or parapet wall above them; that is to say they are so tightly wedged into the arch as to overcome the outward tendency.

Fig. 42 is an exact drawing of the end development, an oblique arch of 25° obliquity for full semi-circular right section.

# REFRIGERATING AND ICE-MAKING MACHINERY AND APPLIANCES.

By T. LIGHTFOOT.

Read before the Institution of Mechanical Engineers.

## II.

III.—*Machinery by which a Gas is Compressed, partially Cooled while under Compression, and further Cooled by Subsequent Expansion.*

This subject having been dealt with in a paper on "Machines for Producing Cold Air," which the author had the honor to read before the members of this institution in January, 1881, the remarks under this head will therefore to a large extent be supplementary to that paper, and will refer chiefly to improvements which have been effected since that date. It will be convenient, however, and will tend to a better appreciation of the subject, to present concisely some brief considerations respecting the physical laws relating to this system of refrigeration, even at the risk of repeating part of the matter touched upon in the previous paper. The intrinsic energy of a permanent gas, or its capacity for performing work, depends entirely upon its temperature. Increase of pressure imparts no additional energy, but merely places the gas in such a condition relatively to some other pressure as to enable advantage to be taken of its intrinsic energy by expansion. Thus, a pound of air at ordinary atmospheric pressure has the same intrinsic energy as a pound of air at 50 lb. pressure above the atmosphere so long as their temperatures are the same; but in the former case no part of the energy can be made use of by expansion without the removal of, at least, a part of the equal and opposite resistance of the atmosphere, while in the latter case expansion can take place freely until the pressure is reduced to that of the atmosphere. As mechanical work and heat are mutually convertible, it is obvious that, if during the expansion a gas is caused to perform work on a piston, its supply of heat must be drawn on to an extent measured by the thermal equivalent of the work done, provided no extraneous source of heat exists from which the deficiency can be made good; and the gas after expansion will be colder than it was before expansion. Expansion behind a piston without the addition of heat from an extraneous source is called adiabatic expansion; and the following are the relations between temperature, volume, and pressure for any two points in the same adiabatic curve:

$$\frac{t}{t_1} = \left(\frac{v_1}{v}\right)^{\gamma-1} = \left(\frac{p}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

where $t$ and $v$ and $p$ denote absolute temperature, volume, and absolute pressure before expansion, and $t_1$ $v_1$ $p_1$ those after expansion, while $\gamma$ is the ratio of the specific heat under constant pressure to that with constant volume. During adiabatic compression the converse results take place, and the same relations exist between absolute temperature, volume, and absolute pressure, as during expansion: $t_1$ $v_1$ $p_1$ denoting those before compression, and $t$ $v$ $p$ those after compression.

In the succeeding remarks reference will be made to the use of ordinary atmospheric air alone; for although in one or two special instances this class of machinery has been applied to the cooling of some of the more volatile hydro-carbons, its almost universal application at the present time is for the cooling of air, which therefore will alone be dealt with. The amount of aqueous vapor present in the atmosphere varies from that required to produce saturation down to about one-fifth of that quantity. At any given temperature a volume of saturated air can contain only one definite amount of vapor in solution; and if from any cause additional moisture be present, it cannot exist as a vapor, but appears as water in the form of fog or mist. The temperature of saturation, or the dew points, varies according to the quantity of vapor

in solution: the smaller the quantity, the lower is the dew point. The capacity of air for holding moisture is also affected by pressure: a diminution in volume under constant temperature reduces this capacity in direct proportion.* In the former paper reference was made to various means that had been devised for ridding the air more or less completely of its contained moisture, in order to obviate as much as possible the practical evils resulting from its condensation and freezing: this being at that time considered one of the most important points in the construction of cold-air machinery. Since then, however, experience has demonstrated that these evils were much exaggerated, and that the condensation of the vapor and deposition of the moisture in the ordinary cooling process after compression, which is common to every cold-air machine, are amply sufficient to prevent any serious deposition of ice about the valves and in the air passages: provided, firstly, that these valves and passages are well proportioned, and, secondly, that proper means are adopted for obtaining in the coolers a deposition of the condensed vapor, which would otherwise pass with the air into the expansion cylinder in the form of fog, and become converted into ice. Reference to the table shows that, if the compressed air be thoroughly deprived of its mechanically suspended moisture, the amount of vapor entering the expansion cylinder is extremely small. Another matter from which the mystery has now been dispelled is the meaning of the term "dry" air, so much used by the makers of cold-air machinery; this is a point that was just touched upon towards the close of the discussion upon the previous paper. No doubt it is still to a large extent popularly supposed that, unless the air be subjected in the machine to some special drying process, it will be delivered from the expansion cylinder in a moist or damp state, and in consequence be unfitted for use in the preservation of perishable food and for other purposes. But no such state could really exist; for whether the air be specially "dried" or not, its humidity when delivered from the expansion cylinder is precisely the same, so long as its temperature and pressure remain the same, in as much as in practice it is always in a saturated condition for that pressure and temperature. The difference lies in the amount of ice formed, which of course is greater if the amount of moisture entering the expansion cylinder is greater; but this quantity, as has been already stated, may in the author's opinion be brought down within perfectly convenient limits by a proper construction of the cooling vessels. In his latest machines, therefore, all special drying apparatus has been dispensed with: the air being simply compressed, passed through a surface cooler, and expanded back to atmospheric pressure. On the other hand, Messrs. Haslam & Co., of Derby, still apply an interchanger, on somewhat the same principle as that previously described in connection with the Bell-Coleman machine (*Proceedings*, 1881, page 111); and it would be interesting if some definite particulars could be furnished to show what practical effect this interchanger really has.

Messrs. Hall's cold-air machine is of both horizontal and vertical type, the latter applying to the smaller sizes. In either case, when combined with a steam engine, it consists of three double-acting cylinders placed side by side, at the end of a frame or bedplate; the cylinders are furnished with the usual moving parts, and the connecting-rods work on three crank-pins on a common crank-shaft. One of the cylinders is used with steam in the ordinary manner, for giving the requisite motive power. Of the two others, one is for compressing and one for expanding the air. The coolers are of the multitubular type for surface cooling, and are placed in the bedplate or frame. The valves for the compression and expansion cylinders are slides of somewhat peculiar design, worked from a pair of weigh-bars, one for the main and the other for the expansion slides. The valves are placed on the under-side of the cylinders, which renders them rather difficult of access; but in the larger sizes of machines the cylinders are raised, and work down to the shaft at an angle, which gives a little more room below. The compressor is water jacketed; and so far as the author is aware no special arrangement for drying the air is employed.

* For the quantity of vapor necessary to produce saturation, reference may be made to the table and formula given in the appendix to the paper on "Machines for Producing Cold Air" (*Proceedings*, 1881, page 122).

The Haslam dry-air refrigerator, which has been very largely adopted, is also made both horizontal and vertical, the horizontal type applying to large machines, and the vertical to those of small size. The cylinders are double-acting, and their arrangement with regard to one another varies in different classes of machines. The compressor is water-jacketed, and discharges into surface coolers placed in the bed. The compressed air, after having been cooled in the ordinary way by water, is further reduced in temperature in an interchanger, by the action either of the spent cold-air on its way from the chamber in which it has been utilised, or of the cold air as it leaves the expansion cylinder; and in this manner a further condensation and deposition of moisture are brought about. The expansion cylinder presents no peculiarity in design, with the exception of the exhaust valves, which are separate from those admitting the air, and are so arranged as to offer as little obstruction as possible to the passage of the air. The Haslam Company also manufacture the Bell-Coleman machine, which was described in the author's previous paper.

In a horizontal dry air refrigerator of the author's design, of the type used for delivering from 20,000 to 60,000 cubic feet of cold air per hour, the compressor is double-acting, and the expansion cylinder single-acting. They are placed close together, tandem fashion, leaving room for examination of the piston, with one rod common to both cylinders. In this way the coldest part of the expansion cylinder is removed from the hottest part of the compressor. The air-valves are circular slides of phosphor bronze, actuated by eccentrics in the usual way. This kind of valve enables the ports to be made very short and direct; and besides being noiseless in action, it allows of a high piston speed being attained. No trouble has been experienced with regard to wear, not a single case having occurred in which the valves have had to be replaced, notwithstanding that some have been in almost constant work since 1882. The air enters the compressor by pipes, and after being compressed passes by another pipe to the coolers, which are placed in the bedplate, and consist of a couple of iron vessels containing clusters of solid-drawn Muntz-metal tubes of $\frac{3}{4}$-inch external diameter. Water is circulated through the inside of the tubes by a pump, the supply passing in by one pipe, through the tubes, and away by another pipe to the compressor jacket, whence it escapes by a third pipe. The water condensed and deposited from the air in the coolers is blown off from time to time by means of drain cocks, or may be discharged automatically. The compressed air passes through one cooler and returns through the second, being cooled to within some 5° or 6° of the initial temperature of the cooling water, which circulates in a direction opposed to that of the air. The quantity of water required is at the rate of from 30 to 40 gallons for every 1,000 cubic feet of cold air discharged at atmospheric pressure, that is, from three to four times the weight of the air; but the quantity varies in different machines according to the efficiency of the apparatus. From the coolers, the air passes by a pipe to the expansion cylinder; and after performing work upon the piston, and returning about 60 per cent. of the power expended in its compression, it is exhausted from a passage, having become cooled down to from 70° to 90° below zero Fahr. The steam cylinder is overhung from strong brackets cast on the bedplate, and is arranged so that a jet or surface condenser can be placed below, with an air pump worked from a continuation of the piston-rod; the space occupied is thus practically the same, whether the engine is noncondensing or condensing. The arrangement also lends itself readily to the application of a second steam cylinder, tandem fashion, for working on the compound principle.

For land machines to deliver more than 60,000 cubic feet of cold air per hour, the vertical type is adopted, and the compressor is made single-acting as well as the expansion cylinder, while a horizontal compound condensing steam-engine is used for giving the necessary motive power. A machine to deliver 285,000 cubic feet of cold air per hour, for cooling a large market, is now being designed in this way. The compressor is furnished with an internal pipe, from which a spray of cold water continually plays on the back of the piston and on the sides of the cylinder, but never comes in contact with the air itself. In order to secure com-

pactness and simplicity, machines delivering less than 20,000 cubic feet of cold air per hour are made, the compressors being single-acting. The smaller sizes are very frequently made on the vertical plan, for use both on land and on board ship. The design is practically the same as that of the horizontal machines; but in the vertical type the coolers are cast in one piece with the frame, instead of being separate. There is a vertical machine of similar design, but arranged for being driven by a belt. The main objects kept in view by the author in designing all the foregoing machines are economy of production, efficiency, and simplicity, Some thirty of these refrigerators, of one form or the other, have now been made and put to work since 1884; and in not one single instance has any breakdown occurred in working, nor have any repairs been required beyond those that would have been necessary to an ordinary steam engine of good construction. In many cases machines made in England have been packed and shipped to Australia, and to North and South America and other foreign countries, where they have been erected and put to work without the assistance of any skilled labor from this country. With regard to the power expended in cooling air on this plan, it may be stated that, in the best machines of large size now made, a weight of 1,000 lb. of air per hour can be reduced from 60° above to 80° below zero, with cooling water at 60° Fahr., with the expenditure of about 18 indicated horse-power. This is equal to an abstraction of 916 units per pound of coal, with an engine using 2 lb. of coal per indicated horse-power per hour.

IV.—*Considerations as to the Applications of the Various Systems.*

Under this head it is not intended to deal with the class of apparatus first described—for abstracting heat by the rapid melting of a solid, inasmuch as, excepting for domestic purposes in localities where other ice is not available, its application is wholly special and very limited, being confined almost entirely to the laboratory. Nor in regard to the machinery and apparatus in the second class—for abstracting heat by the evaporation of a more or less volatile liquid—need much be said, so far as ice-making and ordinary cooling are concerned; the various systems have already been explained in considerable detail, and sufficient information has been given upon which to base an estimate as to their economical application under any stated conditions. It is, therefore, chiefly with the machinery described in the third class that the present considerations will deal—namely, machinery by which a gas is compressed, partially cooled while under compression, and further cooled by subsequent expansion in the performance of work. Probably the earliest application of a refrigerating machine to manufacturing purposes was in 1861, when one of Harrison's ether machines was used by Mr. A. C. Kirk for the extraction of solid paraffin from shale oil. Since then the manufacture of paraffin has been developed to a large extent, and at the present time there are very few works engaged in its production without a refrigerating machine of one kind or another.* For the cooling of worts and of fermenting beer in breweries, refrigerating machines are largely employed. With English beer, which it is not necessary to cool below 50° Fahr., the general practice is to reduce the temperature of the cooling liquor by passing it through the refrigerator of the machine, the cooled liquor being afterwards used in an ordinary brewer's refrigerator. For larger beer, however, which is fermented at about 40° Fahr., the liquor is generally cooled by means of brine, and the temperature is brought down nearly to freezing-point. The same machine is in this country frequently employed for circulating cooled brine through a series of pipes above the fermenting tuns as well as for cooling the liquor; while in lager beer breweries the whole of the fermenting rooms and stores are kept, the former at about 42° Fahr., and the latter at about 31° Fahr., by means of cold brine circulating through pipes placed either on the ceiling or around the walls. For breweries, as well as for paraffin extraction, there can be no doubt that the most suitable machines to employ are those in which the cold is produced by the eva-

* Full information in regard to the most recent practice in paraffin cooling will be found in the *Journal of the Society of Chemical Industry*, May 29 and November 30, 1885, which contains papers by Mr. Beilby, describing the cooling machinery erected at the Oakbank Oil Works.

poration of a volatile liquid. Notwithstanding this, air-refrigerating machines have been applied for both purposes in certain special cases, and have given good results, though at a larger expenditure of fuel. There are many instances, however, in which the extra cost of fuel may be more than counterbalanced by the advantages resulting from simplicity and compactness, and from the absence of all inflammable or corrosive chemicals. Besides this the facility of application of cold-air machines is much beyond that of any other refrigerator. For these reasons they have been applied in dairies and in butterine works; in the latter case an additional advantage is gained from the rapidity with which the cooling can be accomplished, owing to the extremely low temperature at which the air is delivered from the machine.

The most extensive application of dry-air refrigerators, however, has been to the preservation of meat and other perishable foods. Explanations with regard to the general question of preservation by cold have already been fully gone into by the author in a paper on the "Preservation of Foods by Cold," read before the Health Congress at Brighton in December 1881; and it will therefore suffice here to state that, although it had long been known that at low temperatures the decomposition of animal matter was arrested for an almost indefinite period, yet the practical realisation of preservation by cold was prevented from being carried out for want of a simple and efficient means of artificial refrigeration. The attempts that had been made to produce a refrigerated atmosphere by means of ice had not given satisfactory results, owing, no doubt, to the moist state of the air, which, cooled by contact with melting ice, was necessarily saturated, and brought about a musty taste and loss of flavor in the meat preserved in it. In 1878, however, upon the successful development of the cold-air machine, it became possible to produce a cold atmosphere, which, even at a temperature of from 35° to 40°, never contained more than from 50 to 60 per cent. of the moisture required to saturate it. Under this condition all danger from excess of moisture as well as from excessive dryness was avoided; and the dry-air refrigerator was, therefore, speedily adopted for preservative purposes. Machines in which cold is produced by the evaporation of a volatile liquid have also been applied for preserving perishable foods. This has been done, either by cooling the rooms direct by means of overhead pipes through which the cooled brine is circulated, or else by causing a current of air from a fan to impinge against surfaces cooled by an internal circulation of brine, and by then passing the cooled air into the storage rooms. As to whether the air machine or that employing a volatile liquid is the best and most suitable, no general rule can be laid down. The simplicity, compactness, and readiness of application of the air machine have secured it a ready adoption in many cases where chemical machines would have been wholly inadmissible; but on the other hand the author considers that air machines have frequently been entirely misapplied. For use on board ship there can probably be no difference of opinion; and nearly the whole of the meat now imported into this country in a cooler or frozen condition is preserved by means of dry-air refrigerators, while in only one or two cases is a portion of it chilled and frozen on land by chemical machines.

The means adopted for the freezing and preservation of meat are very simple. They consist in lining the room, or the hold of the vessel, with material as impervious to heat as practicable. The construction of the lining is altered in different cases according to circumstances and to fancy; but it may be taken that an outer and inner layer of tongued and grooved boards 1 inch or 1½ inch thick, with a 9-inch space between filled with charcoal, form a fairly good protection, while in some cases silicate cotton may be used with advantage instead of charcoal. A little extra care and expense bestowed on the insulation of a chamber are soon repaid, for when the contents of the chamber are once reduced to the required temperature, the refrigerating machine has nothing further to do than to neutralise the heat passing through the walls, so that the more perfect the insulation, the greater is the saving in fuel, in wear and tear of machinery, and in attendance. The cold air from the machine is usually admitted by ducts placed near the ceiling, and after performing its cooling work it is led back

to the compressor, to be used over again, with the addition of a small amount of fresh air. In freezing, a temperature of about 10° Fahr., or even lower, should be maintained, and the carcases should be hung so that the air can circulate freely around them. If, however, the meat has previously been frozen, as is generally the case with the cargoes brought from abroad, which are to a large extent frozen on shore, the carcases are best packed as close together as possible, taking care to avoid injury through bruising, and to see that a free space is left for the cold air to circulate between the meat and the inner lining of the chamber. The temperature in this case need only be maintained low enough to leave sufficient margin in case of the machinery having to be stopped for any slight adjustment, or for oiling. The capacity of a machine to be applied in any given case is determined by a consideration, first, of the cooling work to be performed on the material contained in the chamber; and, secondly, of the amount of heat that will pass into the chamber from without. With regard to the first, nothing need be said here. The second quantity depends upon the area of the walls, floor, and ceiling, their construction, and the difference between the minimum internal and maximum external temperature. Experience has, of course, laid down certain general rules; but there are always special cases arising which require special treatment, and which can only be considered on the basis here set forth.

The trade in frozen meat has already necessitated the establishment of large stores, where the carcases are received and kept until they are required for consumption. A number of retail butchers also are now adopting cold stores of their own; such a storage arrangement is carried out in the vaults in Leadenhall Market for the preservation of about 20 tons of meat, partly frozen and partly unfrozen. A vertical dry-air machine is driven by an Otto gas engine, and by working from three to six hours per day supplies sufficient cold air for the four chambers. The temperature rises a few degrees during the night, and between Saturday night and Monday morning; but this is not found to be any disadvantage, and it has never yet been necessary to run the machine on a Sunday. The same water that is used for cooling the air cools also the gas-engine cylinder, and is afterwards used for heating the offices. The cost of the gas in this case is 1s. 3d. per hour. In view of the increasing demand for installations of this kind, the author has made arrangements with Messrs. Crossley Brothers to manufacture his dry-air machine in combination with the Otto gas engine, the gas engine simply taking the place of the engine there shown. In this way the cost will be reduced; and space also, which is generally very limited, will be saved. Similar installations have been erected for poulterers, game dealers, and butter salesmen, but need not be further referred to. In addition to the importation of dead meat, refrigerating machines of the horizontal kind shown in the diagrams have been applied for supplying fresh cool air for the ventilation of ships' holds in which live cattle are carried. In this way a temperature of 100° Fahr. has been reduced to 70° in the height of summer, and the loss of cattle has been entirely prevented. No doubt the same system could be equally well applied for the cooling and ventilation of buildings; but so far as the author is aware it has not yet been tried.

There are also arrangements on board passenger vessels for making ice, preserving meat, game, fish, and other perishable foods, cooling water, preserving vegetables, and cooling wine, beer, aerated waters, &c. This is a plan frequently carried out in large passenger vessels, and was introduced, the author believes, by Mr. Manuel, the engineering superintendent of the Peninsular and Oriental Company. The particular arrangement illustrated is one adopted in connection with a vertical steam-driven machine. The course of the cold air is indicated by arrows. In case of the vegetable room becoming too cold, ducts are provided by which the air can be led direct from the meat chamber to the machine. A somewhat similar arrangement of refrigerating plant is used in hotels; and the author's machines have been successfully applied for this purpose in the United States, though not as yet in this country. A recent application, also worthy of notice, is for preserving fish on board steam trawlers and on shore. Last year two of the author's vertical machines were sup-

plied for this purpose, one on a steam trawler, and one on a carrier, for use off the coast of Brazil, almost under the equator, in a climate where fish was hardly known as an article of diet, owing to the previously insuperable difficulties of preserving it in a sufficiently fresh state. The fish as soon as caught are placed on trays in an insulated room maintained at a temperature of about 35° Fahr. The experiment has been perfectly successful, and a further order for similar machinery is now being executed. In 1882 dry-air refrigerators were first applied to the cooling of chocolate by Messrs. J. S. Fry & Sons, of Bristol, who adopted one of the author's horizontal machines with the double-expansion arrangement described in his previous paper. Since then a number of similar machines have been applied for the same purpose in different parts of Europe and in the United States; and works which had to be entirely stopped in summer are now carried on during the whole year. The preservation of yeast, the cooling of gelatine dry plates, of fresh-killed meat in slaughter-houses, and the freezing of tongues in South America for exportation, have all been satisfactorily accomplished by the dry-air machine.

A rather remarkable application of refrigeration was made towards the close of last year by Captain Lindmark, of the Swedish Royal Engineers, who was engaged in the construction of a tunnel for foot passengers through a hill in Stockholm, on the top of which were built residential houses. The workmen came upon some ground, consisting of gravel mixed with clay and water, which had so little cohesion that the ordinary method of excavation had to be abandoned and the works stopped, owing to a subsidence in the earth above, which endangered the safety of the houses. Underpinning was out of the question, on account of the great expense. Under these circumstances it was decided to freeze the running ground, and to use cold air for the purpose as being most readily applied. One of the author's horizontal machines, capable of delivering 25,000 cubic feet of air per hour, was accordingly supplied by Messrs. Siebe, Gorman & Co., and was erected in the tunnel as close as possible to the required spot. The innermost end of the tunnel next the face was formed, into a freezing chamber by means of partition walls, which were made of a double layer of wood filled in between with charcoal. In the middle of last September the works were resumed. After the refrigerator had run for sixty hours continuously, the gravel was frozen into a hard mass to a depth varying from 5 feet near the bottom of the tunnel to 1 foot near the top. At the crown no freezing took place, and, though the temperature at the bottom of the chamber was as low as 40° below zero Fahr., a thermometer placed at the top, 16 feet above the floor indicated 32° above zero. This circumstance, however, was an advantage rather than otherwise, because, in any case, the roof would have had to be supported by planking, which would have been difficult to drive into the gravel had it been actually frozen at that part. The work was proceeded with in lengths of 5 feet, the excavation commencing at the top; and a temporary iron wall made up of plates 12 inches square was built in against the face from the top downward as the cutting away of the gravel proceeded. From 8 to 10 feet up from the bottom no protection was needed, as the frozen gravel formed such a hard, solid mass that it had to be removed with special tools. After once fairly starting, it was sufficient to run the cold-air machine, on the average, from ten to twelve hours every night, excepting after heavy rains, when much water percolated through the gravel. The machine worked all the time without a single hitch., and delivered the air at a temperature of 67° below zero Fahr. The temperature of the freezing chamber was generally from 6° to 15° below zero Fahr. after twelve hours' running; but it soon rose to freezing point when the men began to work. After two 5-feet lengths had been excavated, the partition wall was removed forward; the capacity of the freezing chamber thus varied from 3,000 to 6,000 cubic feet. The arching of the tunnel was completed as rapidly as possible close up to the temporary iron wall, while the ground was still frozen. This method of driving the tunnel was employed through a distance of about 80 feet with entire success. In the residential house to the north, neither subsidence nor cracks were perceptible three months after the tunnel was completed at this point. In the

house to the south, the front has subsided about an inch, causing some small cracks in the walls; but this house was not so well built as the other, subsidences having taken place in it before the tunnel was commenced. The daily progress while using the freezing process averaged about 1 foot. Although this is the first instance in which a dry-air refrigerator has been applied for the freezing of running ground, it is not the first in which refrigeration has been used for that purpose. As early as 1862 an ether machine was constructed by Messrs. Siebe, Gorman & Co., for freezing a quicksand met with in sinking a well. In that case pipes

TABLE I.—FREEZING MIXTURES.

| Composition by Weight. | | Reduction of Temperature in Degrees Fahrenheit. |
|---|---|---|
| Ammonium nitrate | 1 part | From + 50° to + 4° = 46° |
| Water | 1 " | |
| Ammonium chloride | 5 parts | From + 50° to + 10° = 40° |
| Potassium nitrate | 5 " | |
| Water | 16 " | |
| Ammonium chloride | 5 parts | From + 50° to + 4° = 46° |
| Potassium nitrate | 5 " | |
| Sodium sulphate | 8 " | |
| Water | 16 " | |
| Sodium nitrate | 3 parts | From + 50° to − 3° = 53° |
| Nitric acid diluted | 2 " | |
| Ammonium nitrate | 1 part | From + 50° to − 7° = 57° |
| Sodium carbonate | 1 " | |
| Water | 1 " | |
| Sodium phosphate | 9 parts | From + 50° to − 12° = 62° |
| Nitric acid diluted | 4 " | |
| Sodium sulphate | 8 parts | From + 50° to − 0° = 50° |
| Hydrochloric acid | 9 " | |
| Sodium sulphate | 5 parts | From + 50° to + 3° = 47° |
| Sulphuric acid diluted | 4 " | |
| Sodium sulphate | 6 parts | From + 50° to − 10° = 60° |
| Ammonium chloride | 4 " | |
| Potassium nitrate | 2 " | |
| Nitric acid diluted | 4 " | |
| Sodium sulphate | 6 parts | From + 50° to − 40° = 90° |
| Ammonium nitrate | 5 " | |
| Nitric acid diluted | 4 " | |
| Snow or pounded ice | 2 parts | To − 5° |
| Sodium chloride | 1 " | |
| Snow or pounded ice | 5 parts | To − 12° |
| Sodium chloride | 2 " | |
| Ammonium chloride | 1 " | |
| Snow or pounded ice | 24 parts | To − 18° |
| Sodium chloride | 10 " | |
| Ammonium chloride | 5 " | |
| Potassium nitrate | 5 " | |
| Snow or pounded ice | 12 parts | To − 25° |
| Sodium chloride | 5 " | |
| Ammonium nitrate | 5 " | |
| Snow | 3 parts | From + 32° to − 23° = 55° |
| Sulphuric acid diluted | 2 " | |
| Snow | 8 parts | From + 32° to − 27° = 59° |
| Hydrochloric acid | 5 " | |
| Snow | 7 parts | From + 32° to − 30° = 62° |
| Nitric acid diluted | 4 " | |
| Snow | 4 parts | From + 32° to − 40° = 72° |
| Calcium chloride | 5 " | |
| Snow | 2 parts | From + 32° to − 50° = 82° |
| Calcium chloride crystalized | 3 " | |
| Snow | 3 parts | From + 32° to − 51° = 83° |
| Potash | 4 " | |

TABLE II.—EVAPORATION OF LIQUIDS.

| Liquid or Gas. | | Water. | Anhydr's Ammonia. | Sulphuric Ether. | Methylic Ether. | Sulphur Dioxide. | Pictet's Liquid. |
|---|---|---|---|---|---|---|---|
| Specific gravity of vapor, compared with air = 1.000 | | 0.622 | 0.59 | 2.24 | 1.61 | 2.24 | — |
| Boiling-point at atmospheric pressure | | Fahr. 212° | Fahr. −37.3° | Fahr. 96° | Fahr. −10.5° | Fahr. 14° | Fahr. −3.2° |
| Latent heat of vaporisation at atmospheric pressure | | 966° | 900° | 165° | — | 182° | — |
| Absolute vapor tensions in pounds per square inch at different temperatures. | Fahr. | Lb. | Lb. | Lb. | Lb. | Lb. | Lb. |
| | −40° | — | — | — | — | — | — |
| | −20° | — | 19.4 | — | 12.0 | 5.7 | 11.6 |
| | 0° | — | 30.0 | 1.5 | 18.7 | 9.8 | 15.4 |
| | +20° | — | 47.7 | 2.6 | 28.1 | 16.9 | 22.6 |
| | +32° | 0.089 | 61.5 | 3.6 | 36.0 | 22.7 | 27.0 |
| | +40° | 0.122 | 73.0 | 4.5 | 42.5 | 27.3 | 31.3 |
| | +60° | 0.254 | 108.0 | 7.2 | 01.0 | 41.4 | 44 0 |
| | +80° | 0.503 | 152 4 | 10.9 | 86.1 | 60.2 | 60.0 |
| | 100° | 0.942 | 210.6 | 16.2 | 118.0 | 84.5 | 79.1 |
| | 120° | 1.685 | 283.7 | 23.5 | — | 117.5 | 99.7 |
| | 140° | 2.879 | — | 33.5 | — | — | — |
| | 160° | 4.731 | — | 45.6 | — | — | — |
| | 180° | 7.511 | — | 62.0 | — | — | — |
| | 200° | 11.526 | — | 81.8 | — | — | — |
| | 212° | 14.7 | — | 96.0 | — | — | — |

formed into a coil of larger diameter than the lining of the well were sunk into the quicksand, which was then frozen solid by circulating cold brine through the pipes. The excavation was then proceeded with, the lining put in, the circulation of brine stopped, and the coil removed. The same plan has recently been adopted by Mr. Poetsch in Germany in connection with the sinking of colliery shafts; but instead of a coil a series of vertical iron pipes are used, arranged in a circle, the effect of course being precisely the same. For driving the Stockholm tunnel, however, it is difficult to see how freezing by means of brine could have been applied, the excavation being horizontal instead of vertical.

Colonel Martindale said that in the year 1881 the London and St. Katherine Dock Company, of which he had the honor to be the general manager, were pressed by some of their Australian friends to make arrangements, for receiving frozen meat and storing and distributing it. They necessarily began on a very small scale. They had a large vault under one of the warehouses about 500 feet long and 64 feet wide, divided originally into four compartments. They made use of it for their storage. They commenced with a small engine, delivering 10,000 cubic feet of air per hour, from Messrs. Hall, of Dartford, and it did excellent work until 1884 when it was removed to make room for a larger one. They now had fifty-six chambers in two vaults. The smallest had a cubic content of 2,273 feet, the largest 9,280 feet, and the total content of the fifty-six chambers was more than 183 cubic feet. The carcases averaged in weight 56, 60, and 72 lbs., and if the chambers could be completely filled they would hold about 59,000 sheep of the first weight, 56,000 sheep of the second weight, and 44,000 sheep of the third weight, but in practice space had to be left to separate different marks and for gangways. A proportionate deduction, therefore, had to be made from what they could otherwise store; still they could always store forty-four

thousand sheep of the largest size. The construction of the chambers had varied a little in detail, but the last that had been built was according to the recommendation of Mr. Haslam, of Derby. There was a 1¼-inch boarding of rough boards on a concrete floor, and 4-inch bearers, at about 20 inches apart, to carry the floor; which was in two thicknesses of 1¼-inch boards, with prepared brown paper between them. The intervals were filled with carefully dried charcoal. The sides and roofs were similar in construction, and the whole of the boards were grooved and tongued. Air was conveyed by wooden trunks from the machines into the chambers, and pumped into them by slides in the trunks, the air coming in at one end close to the roof, and being drawn in at the other end also close to the roof. Most of the chambers were fitted with return air trunks, which had to be cleared out every twenty-four hours, and the engines' snow boxes about every four hours. A great loss of cold was experienced at every angle, and therefore all rises or falls should be conducted through sloping trunks. A properly insulated air chamber would not rise more than from 24° to 25° in twenty-four hours if the engines were stopped. They had at present four of Haslam's 60,000-feet machines and three of Hall's 30,000-feet machines. They were supplied with steam from the three multitubular boilers of the marine type and four boilers of the locomotive type. If they had to start afresh they would not have any boilers of the locomotive type. They had had to feel their way step by step, and the trade had grown upon them At the A jetty stores, a Haslam 60,000 feet machine was worked on 15 chambers of a total capacity of 48,000 cubic feet capable of storing 11,000 sheep of the average weight of 72 lb., but allowing for gangways, divisions, and marks, that 11,000 had to be reduced to 8,000 or 9,000. The engine was running twenty out of the twenty-four hours, the four hours' stoppage including the necessary time for clearing the valves, snow boxes, and air-trunks. The average speed was 80 revolutions per minute, at an air pressure of 44 lb. per square inch, giving a temperature of 57° below zero in the snow-boxes, and keeping the chambers down to a temperature of from 15° to 18° Fahr. In practice that was found to be about the best temperature at which to keep the meat. About 4½ tons of coal were used in the twenty hours. They had found that it gave better results in proportion to fuel to work at a pressure of 40 lb. to the square inch, instead of 50 lb. and upwards. In keeping such a low temperature in the snow-boxes, a greater volume of cold air was delivered into the chambers, when the proportionate loss in temperature was much less between the delivery from the expansion cylinder to the distant chambers. At the same jetty they had two of Hall's 30,000 feet machines working in fifteen chambers of the same capacity, and doing just about the same work. At the B jetty there were two of Haslam's 60,000 feet machines working on twenty-four chambers of 90,000 cubic feet capacity, and running at an average of 70 revolutions per minute, with an air pressure of 40 lb. per square inch, a temperature of 55° below zero in the snow-boxes, and a coal consumption of 4½ tons in the 20 hours. The loss of temperature in the delivery of air to the chambers at any distance was generally considerable. As a rule the chamber next to the engine was kept at a sufficiently low temperature without opening the delivery ports in the air-trunks. The air was delivered into the next chamber at about 9° Fahr., and into the most distant chamber, 165 feet from the engine, at from 16° to 18° Fahr. The greatest care ought to be taken in regulating the delivery and return air ports, gradually increasing the area in both in proportion to the increased distance. The greatest distance that the air was run was 180 feet. When the temperature of the nearest chamber was at 9° Fahr., they found the most distant chamber was at 18°, and therefore the loss in temperature in travelling was 1° for every 18 feet or 20 feet travelled. He did not want the institution to take that as a scientific result, but it was the practical result of the observations taken by the officers of the company extending over some time. Ninety hundredweight of coal worked the three engines giving out nominally 120,000 feet per hour for twenty hours. That reduced would give 2 lb. of coal required for every 240 feet of air delivered; but in practice they would have to rather increase that amount

because he did not believe the engines actually delivered the total quantity of air that was stated. The coal was ordinary Welsh coal, at about 16s. 6d. per ton. It was also found that from 1 foot to 1½ feet of air per hour would keep cool, say, at 18° Fahr.; 1 foot of storage at a distance not exceeding 180 feet, or at an average distance of 90 feet. The result that he first arrived at was that one foot of air would keep one foot of storage cool per hour, and Mr. Haslam had arrived at exactly the same conclussion, but allowing for delivery, openings, and doors, &c., he did not think they could put the quantity of air required at much under 1½ feet per hour for every foot of storage that they wished to keep down to 18°. If the meat was to remain undisturbed and in large measures, they would probably be able to do with one foot of cool air for every foot of storage.

A communication was then read from Mr. Colyer, in which he stated that one of the first machines made on Mr. Harrison's system was still at work at Messrs. Truman, Hanbury & Co.'s brewery, and was acting very efficiently. It had been there for about thirty years. He thought the consumption of coal actually stated in the paper at 2 lb. per hour was too low, and that 3 lb. or 4 lb. would be nearer the mark. Machines for carrying water and making ice might be divided into two classes: one in which ether was used, and one in which ammonia was used. In London, where coal was dear, and water often had to be obtained from the water companies, the ether system was far more expensive than the ammonia system.

Mr. Gorman said that the machine at Messrs. Truman's was made by the late Mr. Siebe, and was the first made under Mr. Harrison's patent except the one that was taken to Australia.

Mr. Harrison said the latent heat of ammonia was set down in the paper at 900°, and the latent heat of sulphuric ether at 165°, but the practical working latent heat of ether in the ice-making process was 656° instead of 165°. The figures given by Mr. Lightfoot were correct as regards equal weights of the different substances at the atmospheric pressure, but the ice-maker dealt with measures of capacity. A vacuum pump was a measure of capacity, and to apply the latent heat of equal weights to the quantity passed by a pump was of course altogether inaccurate. Then again, the ice-maker did not work at the atmospheric pressure, and all vapors which were used under lower pressure were of greater latent heat. Latent heat was increased in proportion to the tenuity of the vapor, and if the ice-maker worked at a temperature above the atmospheric pressure there must be a deduction for latent heat lost. In that way the latent heat of ammonia had to be reduced from 900° to 845°, because in using ammonia they worked at a pressure in excess of the atmospheric pressure. There were other points connected with the temperature of condensation, which, in his opinion, brought ammonia and ether very nearly on a level. In point of fact, he thought that of all the different refrigerating agents there was no one better than another. If in any case one seemed to be more efficient than another, it was simply because the principle had been better carried out in that process.

Mr. Price Williams said he had recently had an opportunity of examining the refrigerating process on his voyage out to Australia, and he must bear testimony to the admirable way in which it served its purpose. In this country the question of refrigeration for the preservation of meat was really becoming one of very great importance. In a letter to him not long ago, Sir William Armstrong drew a picture of what a terrible thing it would be for this country if the freedom of navigation were destroyed, and if England lost the supremacy of the sea even for one day. Australia was now able to send any amount of food that could be taken here, but it was regarded as a great mistake to freeze the meat. It seemed to be considered that the arrangement must be such that the meat should not be reduced to freezing, but should be kept as near to the freezing-point as possible. As the refrigerating process had been carried out successfully in ships' holds for purifying the air when live cattle were imported, he thought it might be of very great advantage at times to the berths on board ships. He made an estimate, and the engineer agreed with him, that by the expenditure of the small sum of £700 on board the vessel in which he went to Australia, a constant temperature of 60° or 70° might be maintained. If

the P. and O. Company would carry out that suggestion, they would add very largely to the comfort of their passengers, and induce people to make journeys to the torrid zone much more frequently than they did now.

Mr. Halpin said that when once the chamber was got down to the temperature it was desired to run at, of course all the machine then had to do was to overcome the leaks of heat being transferred through the walls. The importance of the covering was therefore very great, because a large amount of power and coal was being used. He had lately made some experiments in Germany with cork as a non-conductor. The French had used that material for many years before, and brought it out in the 1878 Exhibition; but the trouble in the French arrangement was the expense. They took the ordinary cork, and cut it up in slices, and got a good effect, but at very great expense. In Germany, however, all the refuse and waste cork was ground into powder and cemented together again, and it made an exceedingly cheap material. The broad results of his tests were that 92 or 93 per cent. of the transfer of heat was totally arrested; in other words, that only 7 or 8 per cent. of the heat went through.

Colonel Martindale wished to add that if chemicals were used in producing the cold it was an absolute necessity that the air delivered should not have the faintest trace or smell of chemicals. No consignee would keep his meat in any store where he could detect the slightest smell of that kind.

Mr. Schönheyder said that the cold air was admitted near the ceiling of the chamber and the hot air was also taken away near the ceiling. It seemed to him that if, in these cold air machines, there was any chance of snow getting in with the air, it had a great opportunity of doing so when it was admitted near the ceiling, and of falling on to the meat, and possibly deteriorating it. The air might just as well be admitted near the floor. It would then gradually rise as it picked up heat from the carcases, and could be extracted from near the ceiling.

Mr. Lightfoot, in reply said that the snow difficulty had never arisen. He had never found the snow fall on the meat, and if the meat was frozen he did not think it would matter if the snow did fall on it. He did not agree with Mr. Price Williams, but thought that the meat must be frozen. Unless it was frozen decomposition would take place. It might be kept at a temperature of 35° for three weeks, but beyond that time it was impossible, because a slow process of decomposition and of chemical change took place, and the simple question was how much of that could be allowed before the meat was eaten. On the other hand, when the meat was frozen no chemical change of any kind took place. There was a slight mechanical change, and the cellular tissue was to some extent destroyed, and consequently when the meat was thawed there was a loss of juices.

## CORROSION OF THE COPPER OF THE JUNIATA.

By CHARLES E. MUNROE.

From Proceedings of United States Naval Institute.

On October 23, 1882, I received telegraphic orders from the Secretary of the Navy to proceed to New York and examine the Juniata, with the object of ascertaining the cause of the corrosion of her copper. On reporting there I found the Juniata in dry dock, and an examination of her copper showed that the immersed surface had become covered with a pale green, earthy-looking coating, which at the time had become dry in spots, and blistered. Many of these blisters had split, and the coating had flaked off to such an extent that the floor of the dock was thickly strewn with them. While the outer surfaces of these scales were of an apple-green color, the inner was, in the main, of a copper-red color, though in some instances it was black. The surface of the copper where thus exposed was, in the main, of a copper-red color, but in some spots black. Where these

black spots appeared they were imperfectly circular in shape.

In addition to this general action which had caused the incrustation over the entire wetted surface, it was found that several plates had been so corroded as to be nearly or completely perforated. Eleven sheets on the keel, and sixteen on the bottom, most of them below the turn of the bilge, were so badly corroded as to require removal, and there were many others which gave promise of being soon in the same condition. This corrosion did not involve the whole of the plate on which it existed, nor was every plate attacked, nor in most cases contiguous plates, nor did it, in any case observed, extend to the nails or about them. The action was so irregularly distributed about the bottom and on the surface of the plates attacked, that there could be little doubt that the cause at work was a purely local one. Where corrosion had gone on to the extent described, the outline of the spot was irregularly circular in shape, and the areas decreased unevenly from the outer surface inward, giving to the perforation an irregular cone-shape of very wide angle, the sides of the cone being in steps. The copper at these points seemed to be laminated.

Further inspection showed that a portion of the copper on the keel, and all of the copper on the rudder, was covered with a greenish incrustation which was harder, firmer, and more coherent than that on the remainder of the ship, and that this copper was *wholly* free from any evidences of corrosion. The portion on the keel was midway fore and aft at the top of the keel. It was a goring-shaped section, and, roughly estimated, it was fifty feet in length, and tapered from eighteen inches wide midway to a point at either end. Although this strip was wholly free from local corrosion, yet sheets of copper below it, on the keel, and above it, on the hull, were corroded as described. So on the stern there were several corroded sheets, while the copper on the rudder, immediately adjacent, was free from all evidences of it. From their location it was evident that this copper on the rudder and the top of the keel had been subjected to the same conditions of exposure after immersion as the remainder of the copper on the immersed surface.

The history of the Juniata was officially given as follows: When she had received her suit of copper, she was removed from the dry dock and lay in the Wallabout, under the iron derrick, for about five months; she was then moved to the wharf at the foot of Main street, near Store No. 30, where she lay for one and a half months. From there she was moved to the ordnance dock, where she remained three days; again moved to the foot of Main street, where she lay for a day and a half, and then was taken into the dry dock again. This was two days before I reported in New York. The corrosion noted had consequently taken place during the six to seven months in which the vessel was lying in the Wallabout. The copper on the rudder and the goring-shaped section on the keel were said to have been a portion of the old suit of copper which had been put on at the League Island Yard some years before. The goring-shaped piece owed its form to the fact that the ship was "hogged," and when pieces were inserted to straighten up the keel, it was thought unnecessary to strip the old copper from the old keel.

My attention was next turned to the examination of the new, unused copper from which the copper for the Juniata had been taken. I first, while examining the bottom, inquired of the workmen if they had noticed any peculiarity in the appearance of the copper as they put it on, and I found that they had remarked upon the "picturing," as they termed it, which seemed to be unusual. I applied then for sheets of copper from the same batch, and found that a few remained in the storehouse. On inspection I found that this "picturing" of which the workmen spoke was in the form of irregularly circular black spots and streaks on the surface of the copper. My first impression was that these spots were probably due to the fact that during transportation moisture had gathered on the surface of the plates, and that this moisture had absorbed hydrogen or ammonium sulphide from the bilge gases of the ship in which they were transported, and that this had tarnished them; but on examining the spots by light reflected at a wide angle, and by the sense of touch, it seemed probable that the plates had been rolled since the spots were formed, since the

lustre on the spots was quite as brilliant as elsewhere on the surface. This theory of staining was not credited in the Constructor's Department of the Yard, as it was generally understood that the sheets were in this condition when put aboard the transport boat.

I next directed my efforts to tracing up the history of the Juniata copper. I hoped to ascertain when it was received and where it was rolled; then from the marks upon the sheets to learn from what batch of copper it had come; then to follow up these cakes to the smelting works, and from this point determine the source and character of the ore from which it was made. With this knowledge of the source of the copper and the various processes through which it had passed, I hoped to discover the source of any physical or chemical imperfections which the sheets might contain; but at the outset I found that there were no marks upon these sheets of copper by which they could be identified, and that the different invoices received at the New York Yard were so mixed as to be indistinguishable. All that I could learn was that all of the sheathing used was rolled at the Washington Yard. Since such difficulties as have arisen in the case of the Juniata's copper are likely to recur, it will assist materially in discovering the source of the difficulty if the history of the copper is known. I would recommend that hereafter a full record of the copper should be kept, and that each sheet should be stamped in the upper left-hand corner with the number of the batch from which it comes. This mark will be preserved by the lap of the sheet above. That this is feasible is shown by a sheet of the old copper, stripped some two years previously from the Brooklyn, after it had been some years in service, which bears distinctly the following mark in left-hand upper corner, "U. S. N. Y. W., 1866." Starting from this point it will then be possible to compile from the log-books of a ship such statistics regarding the time the copper has been in use, and the conditions to which it has been exposed, as will enable us to determine the average life of copper sheathing—an important fact about which there now seems to be considerable uncertainty.

I next examined the Wallabout, a crescent-shaped body of water, something over 400 feet wide, lying between the Navy Yard proper and the cob dock. With the flood tide the current passes through to the westward, and with the ebb tide it moves to the eastward. Emptying into it are three sewers. At the east end, opposite the ordnance dock, is the Williamsburg sewer, which drains 2,300 acres of improved property, a considerable part being covered by petroleum refineries, chemical works, sugar refineries, and the like. About 500 feet from the dry dock the Brooklyn sewer, which traverses the Navy Yard, empties into the Wallabout. This drains an area of about 550 acres of improved property largely covered by residences. Near Store No. 30 a small sewer empties which drains a portion of the Navy Yard; and near the west end of the Wallabout the Hudson-avenue sewer, which drains 472 acres of Brooklyn, empties. The result of all this sewage flowing into the Wallabout is to modify very considerably the character of the sea water. The first effect observed is that which always takes place where sewage, charged with dissolved and suspended matter, flows into salt water —viz.: the precipitation of the suspended and dissolved matter and the formation of mud banks. This is going on continually in the Wallabout, and one of the largest banks was formed under the iron derrick where the Juniata lay for about five months. So shoal was it that she rested in the mud at low water, and, in fact was probably imbedded in it for the greater part of the time. From this bank I gathered specimens of the mud, and I also got specimens of the bottom from off the ordnance dock. The first was regular dock mud, but the second consisted largely of coal tar. This last was accounted for by the existence about opposite of two large gas works, the "People's" and the "Nassau," while at the west end of the Wallabout there is a third. From the Williamsburgh and the Brooklyn sewers samples of sewage were taken. The color and character of the sewage as it flowed from the sewers showed that the first was from factories, while the second was largely from dwellings. All the samples of sewage and mud were tested immediately after gathering, and all were found to be slightly *acid*. Naturally the character of the

sewage flowing in, and consequently of the water in the Wallabout, will vary with the season, the day, and the state of the tide, so that the examination of only one set of samples is not of any value, except as indicating the character of the water at the time they were gathered. Realizing this, I applied to the Health Department of the City of Brooklyn, and also to Professor Chandler, President Board of Health of New York, for information concerning the sewage emptying into the East River, but no investigation of this sort seems to have been made. Professor Chandler says, however, "There are a great number of petroleum refineries on Long Island at Hunter's Point and at Newtown Creek, and these refineries use enormous quantities of sulphuric acid, some portions of which find their way into the river. There are also chemical factories in Brooklyn—quite a number of them—and possibly their refuse materials are discharged from the sewers, by which the water along that shore may be rendered quite different from ordinary sea water." Through the courtesy of Civil Engineer F. C. Prindle, U. S. N., and Mr. J. H. Raymond, Commissioner of Health of the City of Brooklyn, I have obtained much of the information concerning the sewers which is given above. It would seem likely that considerable ammonia would reach the Wallabout from the gas works, were it not that ammonia has become so valuable an article, and the processes for recovering it from gas works have become so improved as to prevent much of it being allowed to escape. It is probable, too that the considerable deposit of coal tar discovered at the end of the ordnance dock accumulated before these by-products of gas-making had become of any commercial value.

Besides the specimens of mud and sewage, one sheet of new copper from the lot from which the Juniata's copper was probably taken, five corroded sheets stripped from the Juniata, a strip of the copper from the rudder of the Juniata, and a sheet of the old copper which had been stripped from the Brooklyn when she was last recoppered here, were taken for examination.

Before leaving the Navy Yard I examined the pile of old copper stripped from the Brooklyn when she was last repaired. Although this had been in service many years (just how long I could not ascertain), much of it was so strong that it drew out the nails in coming off. Some of the sheets were eaten through in much the same way as was seen in the Juniata's copper, but there were very few of them. Naval constructor W. L. Mintoyne, U. S. N., informed me that sheets of this old copper had been used for covering the anchor hoy used in the Wallabout, that these sheets had been in use thus for about two years, and that during that time the anchor hoy frequently rested on the mud banks, yet the copper was sound. Mr. Mintoyne also described some experiments which he had made with the Juniata's copper. He took sheets from the lot with which the Juniata was sheathed, and coupled them in pairs by blocks of wood. At the time the Juniata was copper he buried one of these pairs in the mud; the second was suspended six feet from the surface of the water, and the third was suspended at the surface of the water at low-water mark. These couples remained until the Juniata was docked in October, 1882. They were then taken out, and all were found unchanged except the couple buried in the mud, and these were only tarnished.

During my inspection of the bottom of the Juniata I was accompanied by Naval Constructor-in-chief T. D. Wilson, U. S. N., and he suggested in explantion of the corrosion that it was due (1) coming in contact with the copper, and that this probably occurred while the Juniata was lying in the mud bank under the iron derrick, as it was rumored that iron chains and other iron articles had been lost in this mud bank from time to time. Since my visit to the Navy Yard this mud bank has been removed by dredging, but I cannot learn that any such articles have been recovered.

Another theory (2) advanced to account for the corrosion is that it was due to the sewage which flows into the Wallabout in such quantity. This was evidently in mind when my orders were drawn, as they read: "Your attention is called to the fact that a large sewer discharges into the Wallabout at a point near the wharf to which the Juniata has recently been moved."

Another (3) is that it was due to impurities in the copper, arising either from imperfect refining, impure ores, or the intentional admixture of foreign and cheaper metals.

Another (4) is that it was due to iron removed by abrasion, or in the form of rust, from the rolls in the rolling mill.

Anoth r (5) is that it was caused by the adhesion of coal tar.

Another (6) is that it was due to physical or chemical differences in different parts of the copper, which were caused by the method of manufacture.

On the 6th of December, 1882, in obedience to orders I proceeded to Washington, and there examined the sheets of corroded copper from the U. S. S. Brooklyn which were sent from Rio Janeiro. The corroded sheets presented practically the same appearance as those from the Juniata. There was the same irregularly circular outline, and the corrosion was seen in all stages, from a roughened surface at the outer edge of the circle to a thin edge at the center. Through the courtesy of the Chief of the Bureau of Construction, I examined the report of the condition of the Brooklyn, with the accompanying drawings. These sketches showed that there was no regularity in the distribution of the corrosion, though most of the corroded sheets were below the turn of the bilge.

On the 9th of December, in obedience to orders, I proceeded to New York to examine the U. S. S. Trenton, then in dry dock. On inspection, I found her copper to be in a very sound condition, so far as local corrosion was concerned, the only corroded plates being six about each of the Kingston valves, one plate on the starboard side in contact with the stern being roughened, but not pierced, and one on the port side forward, just below and in contact with the ram. Besides these, there were a few plates which had been indented and torn slightly, probably through colliding with some object. In addition, I found that one sheet had been removed from the garboard stroke on the port side, about 60 feet aft. I could not learn why this plate had been taken off.

The history of this copper, so far as I could gather it, is as follows: The Trenton was on commission in Europe for some years, and on her return in October, 1881, she was laid up at the New York Yard. I am informed by her commanding officer, Captain F. M. Ramsay, U. S. N., that when she was brought in she was laid alongside the iron derrick, and she was so heavily loaded that it was with great difficulty that she could be forced into the mud bank under the derrick. After lying there some time she was drawn out into the Wallabout, and from that time until she was put into the dry dock, in December, 1882, she lay nearly opposite the mouth of the Brooklyn sewer. The conditions, then, to which her old copper was subjected were almost identical with those to which the Juniata's new copper was subjected, the chief difference being that as the Trenton was heavily loaded, while the Juniata was light, the Trenton probably sank much deeper in the mud bank than the Juniata did.

On December 20, 1882, in obedience to orders I proceeded to Washington to inspect the rolling mill at the Washington Navy Yard, then in operation. Here I witnessed the operations of hot rolling and scaling, and my attention was particularly attracted to the latter process, as it did not seem to be complete, some portions of the scale being adherent after the removal from the bath, necessitating the cleaning of the sheet as completely as possible by mechanical means. As the treatment with the lye and acid was done in a very crude way, by rubbing on with a broom, this may account, in a measure, for the failure to entirely remove the scale or oxide. During my visit I was the recipient of courteous attentions from Commodore T. Pattison, U. S. N., commanding, and from Naval Constructor S. H. Pook, U. S. N., in charge of the rolling mill, and the latter permitted me to take copies of letters, of recent date from the managers of some of the principal rolling mills in the country, from which I extract the following:

Park, Scott & Co., Lake Superior Copper Mills, Pa, say: "The rolls in our mills which have given the most satisfaction are semi-steam chilled." "We are not experienced as to what action seawater may have on sheathing made with iron rolls."

C. G. Hussey & Co., Pittsburgh Copper and Brass Rolling Mills, Pa., state: "For rolling copper we use principally

the chilled-iron rolls, and as far as our experience has gone we find them well adapted for the work. We never knew of any iron from the rolls adhering to the copper, but black spots may be on the copper from imperfect removal of the scale or oxide. That is the only way we can account for black spots or marks."

Hendricks Brothers, New York, write: "We consider chilled-iron rolls the best for the purpose referred to, and when replacing any at our own works, do so with those of that description. The rolling of copper in iron rollers is not detrimental for sheathing, nor would they injure it in any way as regards the action of sea water. The black spots spoken of are not iron, but copper scale or oxide, and do not affect the quality. Copper may be of equal purity, but some are harder than others; the latter are preferred for the sheathing for vessels, on account of the action of salt water upon it."

Pope & Cole, Baltimore, Md., write: "The only suitable material for the construction of rolls for rolling copper is *best iron, chilled.* The arrangements for rolling copper at the Washington Navy Yard are, in our judgment, so good that some time since we availed of permission from head quarters to make copies of the working drawings in your mill, with the purpose of constructing one here, upon your method, in place of our present mill. The methods and surroundings of rolling copper have nothing whatever to do with the action of sea water upon copper sheathing on vessels. The trouble in cases where copper sheathing has become *honeycombed*, or *quickly worn thin* when in contact with sea water is attributable to the fact of the presence of a little silver in copper, which is quickly attacked by salt water. Copper for rolling can be procured which has no silver whatever in it—not a trace. The black specks or spots which you referred to are not iron: they are the oxide of copper. Copper and oxygen have a wonderful affinity for each other, especially when copper is hot or in a molten state. The oxide of copper, or, as known in commerce, "copper scale," is easily removed from sheets by "pickling," and ought to be wholly removed before your sheets are cold rolled. If you will heat a piece of bright polished copper, and then expose it for one moment to the atmosphere, it will so quickly absorb oxygen therefrom as at once to become as black as iron."

During this visit I received the following information from the executive officer of the Powhatan: "The Powhatan was lying at the wharf of the Brooklyn Navy Yard, near the iron derrick, from November 15, 1879, to January 23, 1880, and from December 23, 1880, to March 24, 1881. Shortly after each of the above occasions of her stay off the Navy Yard she went into the dry dock, and upon examination the copper on the bottom of the vessel was found in perfectly good condition." The conditions of exposure of the Powhatan evidently differed from those of the Juniata only in the fact that the latter was lying in the Wallabout during the summer months, while the former was there during the winter. This would, to an extent, probably modify the action.

On December 28, 1882, Commander Pattison, U. S. N., sent me the following samples: Ingot copper, Pope & Cole; ingot copper, Hendricks Bros.; copper cake, Pope & Cole; copper cake from refuse copper refined at the Washington Navy Yard. The ingot copper from Pope & Cole was full of air holes; the rest of the samples were sound, fine grained, and quite free from air holes or cavities, the specimen from the Washington Navy Yard being especially so.

On December 12, 1882, I received the following letter:

"Bureau of Ordnance,
"Navy Department.
"Washington City, Dec. 11, 1882.

"Professor Chas. E. Monroe, Chemist,
"U. S. N., Academy.

"Sir,—In connection with the condition of the copper sheathing on the Brooklyn, I beg leave to say (as probably throwing some light on the subject) that the copper on the ferry boat Billow, at the Torpedo Station, put on in May last, is very badly pitted.

This metal was furnished by the Bureau of Construction and Repairs, and the following analysis made* at the Torpedo Station shows that it contains foreign matters:

* By Professor J. Fleming White.

| | Per cent. |
|---|---|
| Copper | 98.492 |
| Lead | 0.172 |
| Arsenic | 0.290 |
| Nickel | 0.102 |
| Cobalt | 0.010 |
| Iron | 0.570 |
| Oxygen | 0.240 |
| Zinc | 0.272 |
| | 100.148 |

"Also traces of silver and antimony.

"This copper may have been taken from the same lot from which the Brooklyn was coppered. The Bureau will be glad to make other analyses of copper, if desired. I am, sir, your obedient servant,

"MONTGOMERY SICARD,
"Chief of Bureau."

In reply to my inquiry as to the conditions to which the Billow had been subjected, Capt. T. O. Selfridge, U. S. N., commanding the Torpedo Station, states that "the Billow never has been aground since the copper was put on, and that she has only been exposed to the action of pure sea water."

Learning that there had formerly been trouble from the water of Baltimore Harbor, I addressed a prominent shipbuilding firm there, and received the following reply:

"BALTIMORE, MD., Dec. 14, 1882.

"C. E. Monroe, Professor, U. S. Naval Academy.

"DEAR SIR,—Replying to your favor of 9th inst., in reference to the corrosion of copper and metal on vessels' bottoms in Baltimore Harbor, we would state that previous to the stopping of the sugar refineries and the deepening of our harbor, all the steamboats whose landings were in the vicinity of the refinery or at the foot of the street where the sewage of the latter was discharged suffered very much, and had to be docked for repairs or renewal of metal once each year, and in some cases at the refinery wharves twice in one year. The metal would be eaten worst at the water line around the nails in the seams of the plates. Some of the boats that used iron for protection against ice put it on in the fall and had to remove it in the spring, because it would be eaten away at the water line and interfere with the boat's running. All these boats now run two, three and four years without docking, and if they have pure copper on, we find it good after four years. We have some cases that we attribute to inferior metal. One we have just completed, the ship St. Albans, engaged in the Atlantic trade, metal been on twenty-six months, in active use eighteen months, honeycombed badly and had to be removed; should have lasted forty months. Yours respectfully, etc.,

"WILLIAM E. WOODALL & Co."

In considering the case of the Juniata we must bear in mind that it is to be expected that copper sheathing will corrode in use, and that the peculiar advantage which it offers for keeping a ship's bottom clean is due to the fact that the copper is acted upon by sea water and forms a salt which, as it dissolves or scales, carries off the barnacles or seaweeds with it, and that this corrosion goes on over the whole immersed surface and continues throughout the whole period of immersion.

What takes place with sound copper in pure sea water, will occur in any solvent in which the copper is immersed. If there is no contact with other bodies, solid or gaseous, and no marked currents formed in the liquid, corrosion will take place equally over the whole surface of the copper, though the speed of the corrosion may differ with the solvents.

What is peculiar about the corrosion of the Juniata's copper is that it was local and abnormally rapid. We will now take up the various theories proposed to account for this.

1 and 4. That it was due to contact with iron.

On January 22, 1824, Sir Humphrey Davy said: "The rapid decay of the copper sheathing of His Majesty's ships of war, and the uncertainty of the time of its duration, have long attracted the attention of those persons most concerned in the naval interests of the country. Having had my inquiries directed to this important object by the Commissioners of the Navy Board, and a Committee of the Royal Society having been appointed to consider of it, I entered into an experimental investigation of the causes of the action of sea water on copper.

"It has been generally supposed that

sea water has little or no action on pure copper, and that the rapid decay of the copper on certain ships was owing to its impurity. On trying, however, the action of sea water upon two specimens of copper sent by John Vivian, Esq., to Mr. Faraday for analysis, I found the specimen which appeared absolutely pure was acted upon even more rapidly than the specimen which contained alloy; and on pursuing the inquiry with specimens of various kinds of copper which had been collected by the Navy Board and sent to the Royal Society, and some of which had been considered as remarkable for their durability, and others for their rapid decay, I found that they offered very inconsiderable differences only in their action upon sea water; and, consequently, that the changes they had undergone must have depended upon other causes than the absolute quality of the metal.

"When a piece of polished copper is suffered to remain in sea water, the first effects observed are a yellow tarnish upon the copper and a cloudiness in the water, which takes place in two or three hours. The hue of the cloudiness is first white; it gradually becomes green. In less than a day a bluish-green precipitate appears in the bottom of the vessel, which constantly accumulates, at the same time that the surface of the copper corrodes, appearing red in the water, and grass-green where it is in contact with air."

Pursuing his experiments, Davy showed that there must be free oxygen present in water in order that copper might corrode, for "copper in sea water deprived of air by boiling or exhaustion, and exposed in an exhausted receiver or an atmosphere of hydrogen gas, underwent no change, and an absorption in atmospherical air was shown when copper and sea water were exposed to its agency in close vessels."

From his investigations Davy ascertained that when copper, in contact with a metal which was electro-negative to it, was exposed to sea water, the electro-negative metal was attacked, and the copper was free from corrosion until the other metal was destroyed; and he proposed to protect sheathing by this means. "In pursuing these researches and applying them to every possible form and connection of sheet copper, the results were of the most satisfactory kind. A piece of zinc as large as a pea, or the point of a small iron nail, was found fully adequate to preserve forty or fifty square inches of copper, and this wherever it was placed, whether at top, bottom, or in the middle of the sheet of copper; and whether the copper was straight, or bent, or made into coils. And where the connection between different pieces of copper was completed by wires, or thin filaments of the fortieth or fiftieth of an inch in diameter, the effect was the same; every side, every surface, every particle of copper remained bright, whilst the iron or the zinc was slowly corroded.

"A piece of thick sheet copper containing on both sides about sixty square inches was cut in such a manner as to form seven divisions, connected only by the smallest filaments that could be left, and a mass of zinc of the fifth of an inch in diameter was soldered to the upper division. The whole was plunged under sea water; the copper remained perfectly polished. The same experiment was made with iron; and now after the lapse of a month, in both instances, the copper is as bright as when it was first introduced, whilst similar pieces of copper undefended in the same sea water have undergone considerable corrosion, and produced a large quantity of green deposit in the bottom of the vessel.

"A piece of iron nail about an inch long was fastened by a piece of copper wire nearly a foot long to a mass of sheet copper containing about forty square inches, and the whole plunged below the surface of sea water; it was found, after a week, that the copper defended the iron in the same manner as if it had been in immediate contact.

"A piece of copper and a piece of zinc soldered together at one of their extremities were made to form an arc in two different vessels of sea water, and the two portions of water were connected together by a small mass of tow moistened in the same water; the effect of the preservation of the copper took place in the same manner as if they had been in the same vessel." (*Phil. Trans.* 1824, p. 151.)

On p. 242 *Phil. Trans.* 1824 Davy gives a report of additional experiments on the protection of copper sheathing. He says: "Sheets of copper defended by

from $\frac{1}{400}$ to $\frac{1}{1000}$ part of their surface of zinc, malleable and cast iron have been exposed for many weeks in the flow of the tide in Portsmouth Harbor, and their weights ascertained before and after the experiment. When the metallic protector was from $\frac{1}{40}$ to $\frac{1}{150}$, there was no corrosion nor decay of the copper; with smaller quantities, such as from $\frac{1}{200}$ to $\frac{1}{400}$, the copper underwent a loss of weight which was greater in proportion as the protector was smaller; and, as a proof of the universality of the principle, it was found that even $\frac{1}{1000}$ part of cast iron saved a certain proportion of the copper.

"The sheeting of boats and ships protected by the contact of zinc, cast and malleable iron in different proportions, compared with that of similar boats and sides of ships unprotected, exhibited bright surfaces, whilst the unprotected copper underwent rapid corrosion, becoming first red, then green, and losing a part of its substance in scales.

"Fortunately, in the course of these experiments it has been proved that cast iron, the substance which is cheapest and most easily procured, is likewise most fitted for the protection of copper. It lasts longer than malleable iron or zinc; and the plumbaginous substance which is left by the action of sea water upon it retains the original form of the iron, and does not impede the electrical action of the remaining metal."

In *Phil. Trans.* 1825, p. 328, Davy gave the results of his "Further Researches on the Preservation of Metals by Electro-Chemical Means." He said: "As long as the whole surface of the copper changes or corrodes, no such adhesions (barnacles, etc.) can occur; but when this green rust has partially formed, the copper below is protected by it, and there is an equal action produced, the electrical effect of the oxide, submuriate and carbonate of copper formed being to produce a more rapid corrosion of the parts still exposed to sea water; so that sheets are often found perforated with holes in one part, after being used five or six years, and comparatively sound in other parts.

"There is nothing in the poisonous character of the metal which prevents these adhesions (barnacles, etc.). It is *the solution* by which they are *prevented* —*the wear* of the surface. Weeds and shell fish readily adhere to the poisonous salts of lead which form upon the lead protecting the fore part of the keel; and to the copper, in any chemical combination in which it is insoluble.

"In general, in ships in the Navy, the first effect of the adhesion of weeds is perceived upon the heads of the mixed metal nails, which consist of copper alloyed by a small quantity of tin. The oxides of tin and copper which form upon the head of the nail and in the space around it defend the metal from the action of sea water, and being negative with respect to it, a stronger corroding effect is produced in its immediate vicinity, so that the copper is often worn into deep, irregular cavities in these parts.

"When copper is unequally worn, likewise in harbors or seas when the water is loaded with mud or mechanical deposits, this mud or these deposits rest in the rough parts or depression in the copper. and in the parts where the different sheets join, and afford a soil or bed in which seaweeds can fix their roots, and to which zoophytes and shell fish can adhere.

"As far as my experiments have gone, small quantities of other metals, such as iron, tin, zinc or arsenic in alloy in copper, have appeared to promote the formation of an insoluble compound on the surface, and consequently, there is much reason to believe, must be favorable to the adhesion of weeds and insects."

Up to July, 1824, all Davy's experiments had been tried in harbor in comparatively still water, but soon after the protectors were tested on a steam vessel in the North Seas, and it was found that sheets of unprotected copper one foot square lost about 6.55 grains in passing at a rate of eight miles per hour in twelve hours; but a sheet of the same size defended by rather less than $\frac{1}{500}$ lost 5.5 grains, and like sheets defended by $\frac{1}{10}$ and $\frac{1}{100}$ of malleable iron each lost two grains. These experiments show that there is a mechanical wear of the copper in sailing, and which, on the most exposed part of the ship and in the most rapid course, bears a relation of nearly 2 to 4.55. The copper sheets used weigh from 7,000 to 8,000 grains, and the balance would detect a difference of $\frac{1}{100}$ of a grain in carrying this load.

Further experiments showed that when air was excluded from a vessel containing sea water in which iron and copper or other corrodible metals were immersed, no action took place, and that the addition of an alkaline substance, even in presence of air, was sufficient to arrest corrosion; but if the solution was *strongly* alkaline, then the electro-chemical action was reversed and the copper was corroded while the iron was preserved. The results of applying protecting masses of iron to coppered ships are cited, and the effect seems to have been advantageous; but no instance is given where it had been tested for any long period.

In closing, he says: "The copper used for sheathing should be the purest that can be obtained; and in being applied to the ship, its surface should be preserved as smooth and equable as possible, and the nails used for fastening should likewise be of pure copper; and a little difference in their thickness and shape will easily compensate for their want of hardness."

In the *Comptes Rendus*, 59, 15, 1864, M. Becquerel reviews Davy's work, and records the work which he himself carried on at Toulon under the direction of the Minister de la Marine, which confirmed the views as to the protective action of iron on copper when immersed in sea water.

In the *Trans. Inst. Nav. Arch.*, 10, 166, 1869, John Grantham, Benjamin Bell, Charles Lamport, John Scott Russell, and C. F. J. Young, all testify to the destruction of iron in contact with copper, and the latter quotes Faraday, Wood, Normandy, Selwyn and Siemens in support of his views. These conditions, however, only hold true for sea water in an acid or neutral condition. At the time of my visit to the Wallabout I found the water and mud slightly acid, and if this be the prevailing condition of the Wallabout, it is impossible that the corrosion of the copper could have been due to the presence of iron.

But while this relative action holds good for acid and neutral solutions in general, in most alkaline solutions, and especially solutions of the alkaline sulphides, the reverse is true and the copper becomes electro-positive and is dissolved, while the iron remains unacted upon. Davy pointed this out in 1812 (*Chemical Phil.*, p. 148), and again, in 1825 (*Phil. Trans.*, p. 339); and Faraday, in his *Experimental Researches in Electricity*, Vol. II., p. 86, gives tables of the electro-chemical series for different solutions which show these facts. In order to test these statements I made experiments, taking solutions of ammonium carbonate and Severn-River water, and ammonium sulphide and Severn water. In each of these I inserted a strip of iron and one of copper in contact with each other and allowed them to stand. In 24 hours there was evidence of corrosion on the copper, and in one case where the action had gone on for two months, the copper was eaten off to the surface of the liquid, and copper was deposited on the iron. The solution contained 10 cm. of yellow sulphide of ammonia of the ordinary strength to 200 cm., of water, and during the time spoken of the solution was in an open flask in a dimly-lighted hood. No quantitative experiments were made, since it was not important for this research in the case of the ammonium carbonate, and in the case of the ammonium sulphide the coating of sulphide on the copper made it difficult to determine the loss with any degree of accuracy.

In determining if such a condition of circumstances could occur in the Wallabout we may learn something from the examination of the sewage waters and mud. The sewage water taken at the mouths of the sewers was collected in patent-stoppered lager-beer bottles, which were carefully rinsed with the water to be collected. Although tolerably free from odor when collected, by the time they reached Annapolis they were highly charged with gases, which proved to be largely sulphide of hydrogen and some sulphide of ammonia. Through decomposition they had become much more turbid from suspended matter than when first collected. So great was the pressure upon the bottles that, though they were kept in a cool place, one of them burst under the pressure of the confined gases. The sewage had become alkaline when it reached Annapolis. I give below the analyses of these waters, filtered, and of the sedimentary matter, and I add an analysis of the Severn-River water, since I used this in some of the

experiments. The analyses given hereafter are usually the mean of several:

Parts in 100,000.

| | Solids. | | | Ammonia. | | |
|---|---|---|---|---|---|---|
| | Vol. | Non-vol. | Total | Am. Al | Am. | Salt. |
| Wm'sb'g | 261.6 | 583 6 | 845 2 | .1420 | .1250 | 385.5 |
| B'klyn... | 118 6 | 160.8 | 279.4 | .0758 | .0472 | 135.2 |
| Severn.. | 150.0 | 1236.0 | 1393.0 | .... | .... | 1054.7 |

SUSPENDED MATTER.

Parts in 100 000.

| | Vol. | Non-vol. | Total. |
|---|---|---|---|
| Williamsburgh..... | 31.2 | 84.0 | 114.2 |
| Brooklyn..... | 22.6 | 38.1 | 50.7 |

The result of such sewage as the above flowing into salt water must be, not only the production of mud banks, as stated above, but also the generation of hydrogen sulphide and alkaline sulphides, for the salt water contains calcium sulphate (in pure sea-water it will rise to 100 parts in 100,000), and when organic matter comes in contact with this, calcium sulphide is formed, which gives off its sulphur as hydrogen sulphide when it comes in contact with the carbon dioxide of the air. Ammonium sulphide will then be formed through reaction with the sewage.

MUD.

The mud was stored in new paint-kegs immediately after collecting, and on arrival here it was transferred to air-tight glass jars. When the mud from under the iron derrick was dried, it was of a bluish-white color, and contained a considerable number of shells. It effervesced somewhat with acids, and when moistened it had a clay-like appearance. On drying, it gave off a slight offensive odor of animal matter. The mud from off the ordnance dock appeared, on drying, to be a mixture of blue mud with coal-tar, and gave off the odor of coal tar on drying. The mud from the iron derrick lost 15.23 per cent. of volatile matter on ignition, while the mud from the ordnance dock lost 24.51 per cent. When treated with ether, both yielded a yellow extractive matter, which on evaporation gave off an acrid odor. Both samples, after exposure, became alkaline.

We see, then, that in the sewage emptying into the Wallabout we have materials for the formation of ammonium and other sulphides, and that, although at the time of my visit there the water was acid to neutral, yet, under the varying conditions prevailing, it is possible there are times when it may be alkaline. Is it, then, probable that iron in alkaline solution was the cause of corrosion? I think not, and for the following reasons:

If iron had fallen into this mud bank, it is probable that owing to its greater relative weight it would sink through the soft mud to the bottom. Now, there was considerable difference in height between the corroded plates highest up on the hull and those on the keel, and if the Juniata touched bottom on the keel, the iron in contact with the higher plates must have been buoyed up. Since, however, there was room for the much heavier Trenton to get in, it is probable that the Juniata did not touch hard bottom. This argument may, however, be met by supposing that both the vessels lay in a trough in the bottom of the Bay.

Another consideration is that the corrosion is too local for simple contact. None of the holes were over two inches in diameter, nor the roughened spaces about them more than eight inches. Now, copper is a good conductor, and with sheets as thick as these it seems strange that the action should be confined to so small an area. I do not lay much stress on this point.

What seems to me conclusive is that both the Powhatan and the Trenton lay in the same berth without injury, and that the copper on the rudder of the Juniata and the goring-piece on the keel were under precisely the same conditions as the remainder of the copper on the Juniata, and they were not corroded; and finally, that the copper on the Billow was corroded in a similar way without having been exposed to like surroundings.

2. That it was due to sewage. Since household sewage may contain sodium carbonate and hyposulphite from the soap used and zinc chloride and bleaching powder from the disinfectants employed, I tested the action of these substances upon both copper and oxide of copper, the substances and the solutions being enclosed in stoppered bottles. The following are the results after seven months' action:

Copper and sodium hyposulphite—copper coated with sulphide—no copper in solution.

Copper oxide and sodium hyposulphite—no copper in solution.

Copper and sodium carbonate—copper

quoted with green carbonate—considerable copper in solution.

Copper oxide and sodium carbonate—faint trace of copper in solution—the copper oxide unchanged in appearance.

Copper and zinc chloride—deep green deposit of copper chloride on sides of bottle—copper bright.

Copper oxide and zinc chloride—no action.

Copper and bleaching powder—copper coated with bluish coat—copper in solution.

Copper oxide and bleaching powder—trace of copper in solution.

All of these substances act upon the copper, but the last two would be destroyed by the organic matter in the Wallabout, and the first two would probably not exist any length of time in their original condition. But granted that any of them were present and free to act, or that there were free acids or ammonia or ammoniacal salts present, could they produce such corrosion as took place on the Juniata? In my opinion not, because they would be dissolved in the water or in a layer at the surface, and would produce corrosion over the entire immersed portion of the copper or else at the water line, while that of the Juniata was purely local and confined to widely and irregularly separated spots.

3. That it was due to impurities in the copper arising from imperfect refining, impure ores, or the intentional admixture of foreign and cheaper metals.

In the paper by Davy quoted above, it will be seen that the presence of iron, tin, zinc, arsenic and the like, in small quantities, promoted the formation of insoluble scale on copper. In Pope and Cole's letter we see that they attribute corrosion to the presence of silver. This view was advanced by A. A. Hayes (*Am. Jour. Sci.* [2] 11,324). He says: "Some analyses I made, many years since, of sheathing copper which had long resisted the action of sea water proved the presence of one ten-thousandth part of silver. It was found that even this small portion of silver sensibly modified the chemical relations of the metals and observations had indicated that the quality for sheathing was improved. Copper of this kind is frequently met with in commerce, and is derived from the Chilian ores of copper, which, although argentiferous, do not yield enough silver to render its separation economical.

"An occasion offered for again examining this subject, when the argentiferous native copper of Lake Superior was first refined and rolled by the Revere Copper Co., more than five years since, and the results have lately been obtained. Four suits of sheathing for large merchant vessels, formed the subjects for observations, the metal being of uniform composition, as determined by assay of the clipping from many sheets. Two thousand parts of the alloy contained four parts of pure silver, or the standard ton of this country contained four pounds of silver (0.20 per cent.).

"A *proximate* analysis of this metal was also made, and it proved to be pure copper throughout, the mass of which, an alloy of silver and copper, was evenly distributed so as to form either a mixture or a compound alloy, in which one part of the copper is truly combined with the silver, and the other and larger part simply combines with the alloy. This is a very common constitution of alloys, in which two metals exist without any metalloid occurring to disturb the simplicity of the union, and always indicates a careful purification of the metals.

"It was assumed as probable that the silver alloy would close the pores of the copper, which takes place with a tin alloy in bronze, and, in a mechanical way, confers durability. If, however, corrosion should take place, it was in accordance with observed cases that the silver alloy would act as a negative element, and the copper alone would be removed. How erroneous these inferences proved will be seen in the detail of the results.

"The Chicora was coppered January 9, 1847, taking 7,392 pounds of metal, which was fastened with bronze nails. She was employed in trade to China, and wore her copper so rapidly that it was removed in March, 1849, 2,628 pounds only remaining. In this case the sheets, after the usual operations, had been consolidated by 'cold-rolling.'

"The Serampore was coppered January 18, 1847, requiring 8,447 pounds of 'cold-rolled' metal, secured by bronze nails. She sailed to China and home *via* Cape of Good Hope, and to the Pacific and home *via* Cape Horn, requiring new copper in March, 1850. The weight of

the remaining copper was not ascertained.

"The Hamilton was coppered October 22, 1847, requiring 7,706 pounds metal, secured by bronze nails. The sheets used were in the ordinary or annealed state. This vessel was employed in the India trade, and wore out her copper in August, 1849. The weight of the copper remaining was 3,086 pounds.

"The Carthage was coppered November 26, 1847, requiring 8,727 pounds 'cold-rolled' metal, fastened by bronze nails. She was employed in the India trade, and her sheathing was destroyed in August, 1849. The copper remaining weighed 5,810 pounds.

"Omitting the case of the Serampore, where the corrosion cannot be determined by weight, we have the loss in every one hundred parts of metal, for the time of duration, thus: The Chicora, twenty-seven months, lost 64.45 per 100; the Hamilton, twenty-three months, lost 59.95 per 100; the Carthage, twenty-one months, lost 33.45 per 100.

"Allowing the same rate of corrosion, and taking the time as 27 months for each: The Chicora lost 64.45 in 100; the Hamilton lost 70.38 in 100; the Carthage lost 43.00 in 100.

"In the cases of the Hamilton and Carthage we perceive the influence of the different processes of manufacturing the sheets on the durability of the copper. By the operation of 'cold-rolling' the surfaces of the sheets are rendered very compact, and in any corroding solution they bear a negative relation to the metal in the same sheets between these surfaces. Such copper is also always strongly negative to annealed copper in acid solutions until the hardened surfaces are removed; it then loses this relation. The Hamilton exhibits the greatest effect of sea-water action on the annealed alloy, while in the Carthage the protecting influence of the hardening surface was exerted nearly to the time her copper was removed. These observations establish the fact of the rapid corrosion of an alloy thus constituted, and show its entire unfitness for sheathing purposes.

"The average duration of copper sheathing decreases slightly as the requirement of greater speed in sailing is more urgent. Taking one hundred merchant ships, sailing on different oceans, the average duration now on American ships is three years.

"On the point of the *kind* of corrosion following the exposure of the alloy to sea water and air, the information obtained of these trials is of a definite character. Part of the sheets remaining, and an ingot of the copper from smelting a large quantity, were assayed, and the results showed that the same proportion only of silver remained as was originally contained in the alloy. The silver, therefore, by taking the negative state in the mass of the metal alloy hastened its destruction, while its own form and condition were such that it separated as the copper was corroded."

In this connection I made the following analyses. In these analyses I designate the copper from the rudder of the Juniata as "rudder copper," that taken from the Juniata after corrosion as "old Juniata copper," that taken off from the Brooklyn, in order to put on her present suit, as "Brooklyn copper," and the new sheet from the New York storehouse as "new Juniata copper."

In the analyses of the coppers, I have followed the methods given by Andrew A. Blair, chemist to the United States Board for Testing Metals, which appear as an appendix to Ex. Doc. 98 of the Forty fifth Congress, Second Session; and I have also employed the method of W. Hampe, given in *Zeitschrift für Analytische Chemie*, 176, 1874, and in Watts' *Dictionary of Chemistry*, Vol. VIII, Part 1. The methods have sometimes been modified in a measure, to accommodate them to the appliances at hand. In the table, the "rudder copper" is No. 1; the "Brooklyn," No. 2; the "new Juniata," No. 3, and the "old Juniata," No. 4. The results given are the mean of a number of determinations:

| | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| Copper... | 99.428 | 99.225 | 98.426 | 98.509% |
| Silver..... | .125 | .085 | .005 | .010 |
| Arsenic... | trace. | none. | .135 | .159 |
| Antimony. | none. | none. | .008 | .005 |
| Lead..... | .010 | 0.80 | .178 | .152 |
| * Iron.... | .183 | .252 | .050 | .580 |
| Nickel.... | none. | none. | .050 | .010 |
| Zinc..... | none. | none. | .170 | .150 |
| Bismuth.. | .005 | .003 | .012 | .015 |
| Oxygen... | .155 | .185 | .280 | .235 |
| | 99.906 | 99.830 | 99.914 | 99.825 |

* In examining the copper for iron, I deemed it important to test the nitric acid used, although it was

For comparison with these, I have sought to obtain analyses of different American coppers from the principal sources, in order that we might determine what would be termed "pure copper" in commerce here, but I have been unable, as yet, to obtain such, so I give (1) an analysis of a "refined copper," from Oker, made by Hampe, and reported in Fresenius' *Quantitativen Chemischen Analyse*, 2, 527; 1882; (2) an analysis of a "refined copper" from Colorado, made by T. Egleston. Ph. D., and given in *Trans. of American Institute of Mining Engineers* for October, 1882; (3) an analysis of "ingot Lake Superior copper" Andrew A. Blair, *loc. cit.* 295.

| | 1. | 2. | 3. |
|---|---|---|---|
| Copper | 99.325 | 99.705 | 99.420% |
| Silver | 0.072 | 0.135 | 0.014 |
| Gold | 0 0001 | .. | .. |
| Arsenic | 0.130 | 0.091 | none. |
| Antimony | 0.095 | . | none. |
| Bismuth | 0.052 | .. | none. |
| Lead | 0 061 | none. | trace. |
| Iron | 0 063 | 0.031 | 0.013 |
| Cobalt | 0 012 | .. | .. |
| Nickel | 0.054 | .. | .. |
| Sulphur | 0.001 | trace. | .. |
| Oxygen | 0.1166 | .. | .. |
| Tellurium | .. | 0.083 | .. |
| Zinc and nickel | .. | 0.024 | .. |
| Suboxide of copper. | .. | .. | 0.537 |
| Carbon | .. | .. | 0.041 |
| | 99.9917 | 100.069 | 100.025 |

The Juniata copper, then, is not so pure as the rudder copper or the Brooklyn copper, or the copper last cited. The excess of silver in the rudder and Brooklyn coppers may at first excite remark, but we must remember that both of these coppers had been exposed to sea water for a very long time, and that sea water contains chloride of silver in solution, and that silver will be deposited upon copper under these circumstances. Mulder, in his *Die Silber-Probirmethode*, 27, states that chloride of silver is soluble in solutions of all the metallic chlorides which are soluble in water. Watt's *Dictionary of Chemistry*, 5, 271, states that silver had been detected in sea water and refers to *Ann. Ch. Phys.* [3] 27, 129, which I have not been able to consult, and T. Sterry Hunt, *Chem. and Geol. Essays*, 231, repeats this statement. To test it, I placed some freshly precipitated and washed chloride of silver in Severn water and inserted a strip of copper. In twenty four hours a decided coating of silver was deposited on the copper.

The amount of silver present in the Juniata coppers seems, however, too small to have been the source of this trouble, and of the other substances found, the oxygen appears the one most likely to have been the cause of the trouble. It should be said that the darker, spotted portions of the new sheets were taken for analysis, and that on especially removing the surface from some of these spots by the aid of a bright steel file scraper, I found it to consist of a film of oxide free from sulphide. But as from the first my attention and that of others had been called to this unusual feature in the copper, and as these spots closely resembled the corroded spots in form, it seemed proper to select these portions. I am not, however, assured that a portion of the oxide did not originally exist in the copper.

The following experiments were made to ascertain if corrosion would take place between copper and copper oxide in the presence of the materials in the Wallabout. Heavy, cold-drawn copper wire was cut into pieces. Each piece was then bent, and one end was heated in the flame until it was coated with oxide. The strips were then immersed in the solutions or buried in the mud, as given in the table below. We then had an electro-chemical couple with copper and oxide of copper. In the experiments cited below, No. 5 and No. 6 were the most satisfactory as regards the cleanliness of the copper after removal from the solution and washing:

bought, as chemically pure, through Desaga, of E. Merch. of Darmstadt. The first bottle examined was but partially full, and had been standing for some time in strong sunlight, and was evolving nitrous fumes, notwithstanding that the glass was of a dark green color. Analysis showed it to contain .00135 gram of iron in 100 cm. Another full bottle of the same lot, which had been standing in the dark, was tested, and was found to be free from iron. This last was used in the analyses.

| Substance used. | Loss. | Remarks. |
|---|---|---|
| | Per cent. | |
| 1. Copper and Williamsburgh sewage | 1 42 | Liquid alkaline—contained coal tar. |
| 2. Copper oxidized and Williamsburgh sewage. | 1.45 | Liquid alkaline—contained coal tar—copper pitted. |
| 3. Copper and Brooklyn sewage | 3.42 | Liquid faintly alkaline. |
| 4. Copper oxidized and Brooklyn sewage | 2.99 | Liquid faintly alkaline—copper pitted. |
| 5. Copper and mud from under shears and Severn water | 7.24 | Liquid faintly alkaline—no pitting. |
| 6. Copper oxidized and mud from under shears and Severn water | 14.64 | Liquid faintly alkaline—copper badly pitted. |
| 7. Copper and mud from Ordnance Dock and water | 4 06 | Liquid alkaline—no pitting. |
| 8 Copper oxidized and mud from Ordnance Dock and Severn Water | 3.06 | Liquid alkaline—copper faintly pitted. |

As in these cases the solutions were all slightly alkaline, I repeated the experiments with Severn River water, and with common salt solutions, and in each case the copper was corroded. In addition, I connected my couple with a galvanometer and got a marked deflection of the needle. Hence there can be no doubt that electro-chemical action can go on between copper and copper oxide in sea water. This view is supported by the fact that all authorities are agreed that the corrosion of pure copper by pure sea water cannot take place in the absence of air. This air supplies oxygen, and the first step in the process of corrosion is one of oxidation. If, then, the copper be oxidized when immersed, the process is facilitated.

5. That it was caused by the adhesion of coal tar. In the examination of the Juniata, no coal tar was observed in contact with the corroded spots, though small amounts were noticed elsewhere, the copper at those points being sound. In the experiments last cited, when coal tar was present it adhered to the copper so firmly that it was difficult to remove it, and it formed a strongly adherent varnish or lacquer which seemed to protect the copper from corrosion.

6. That it is due to physical or chemical differences in different parts of the copper which were caused by the method of manufacture. From the consideration of all the circumstances, and especially of the facts that the copper is found to be *spotted* with oxide; that these spots are irregularly distributed over the plates; that they generally agree in configuration and size with the corroded spots, and that the copper at the corroded spots appears laminated, I am led to conclude that this theory is the more probable one, and that the imperfections result from blister-holes in the copper and the incomplete removal of the scale.

We have found that in the existence of these spots of scale or oxide we have a condition which is favorable to the commencement of the corrosion. Why does it continue?

If we examine one of the corroded spots from which the surface has been removed, we find that the remaining surface is roughened. Now, such a surface is more readily attacked than a polished surface. This latter is a well-known fact in connection with the "rusting" or corrosion of metals, and it is for this reason largely that metal articles are polished. But it seems to me that there is an additional reason for action at this point. In the *Proc. Nav. Inst.* 8, 502 I have shown that annealed steel is much more soluble in sea water than "tempered" or hardened steel, and that when in contact the soft metal is rapidly corroded. I have recently been confirmed in the truth of my observations by the investigation of M. Gruner in *Comptes Rendus*, 96, 195. I am inclined to the opinion that the same holds true of copper of varying hardness, and I find support for my opinion in the statement of A. A. Hayes.* I believe that the copper beneath the

* *Loc. cit.*

spots of scale is softer than that about it, and furnishes the differences necessary for this action.

My theory to account for the existence of these differences and for the formation of the spots is as follows: I assume that an unsound cake of copper is taken for rolling which contains cavities like those seen in the ingot from Pope & Cole. When this is rolled into a bar, the cavities will be extended in the direction of the length of the bar. When the pieces of bar are afterwards rolled into sheets, these cavities will also be extended in the direction of the width of the sheet. These changes in form would of course be irregular, and would tend to produce such shapes as were seen on the copper. These cavities would necessarily contain gas, and copper is a very excellent conductor of heat, while gases are as a rule very poor conductors. Then, when the whole is heated and allowed to cool, the space about the cavity would be longer in cooling than the remainder, and, as a consequence, more scale would be formed at that point than elsewhere, and might adhere more firmly, or its formation might continue after the scaling process was considered complete. This layer of oxide and cushion of gas would then prevent the copper at this point from becoming as hard, through rolling, as over the remainder of the surface. The fact that the copper appears slightly laminated at some of the corroded spots seems to substantiate this theory. It may be objected that an enclosed gas at the high temperature of the operation would exert pressure sufficient to burst the envelope, but we must remember that the cavities were formed when the gas was at the temperature of molten copper.

In conclusion, I would state that I find the source of corrosion of the Juniata's copper to be due principally to the presence of spots of oxide of copper on the surface of the plates, and I would recommend in the future the use of a pure copper, care in the production of sound cakes, and careful removal of the scale.

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# INLAND NAVIGATIONS IN EUROPE.

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A Lecture before the Institution of Civil Engineers.

## II.

### FRANCE.

My description of the chief rivers of France, so far as regards their navigable capabilities, must necessarily be very brief.

The Seine rises on the northern slope of the Côte d'or, at an elevation of 1,460 feet. Its length is 480 miles, and it first becomes navigable near Troyes, about 350 miles from it mouth. Its principal tributaries are the Yonne and Eure, on the left bank,, and the Marne and Oise on the right, and by means of waterways it communicates with the Loire, Saône, Rhine and Scheldt.

From Paris to Tankerville, at the head of the estuary, and 16 miles from Havre, the Seine is so winding in its course that whilst by water the distance is 220 miles, it is only 100 miles in a straight line. From Paris to Rouen, 150 miles by water, and only 72 in a straight line, the river is studded with many islands, and its average fall is 6 inches per mile. At Rouen the level of low water is only 10 feet above the sea. Until the end of last century the low-water depth of the Seine was only $2\frac{1}{2}$ feet, and for nearly fifty years afterwards it was considered to be in a good navigable state when giving a draught of 4 feet. Between 1846 and 1865 numerous locks and weirs were constructed between Paris and Rouen to provide a depth of 5 feet, but before the works were completed it was decided to increase the draught to $6\frac{1}{2}$ feet. The engineers, however, who were entrused with this work, seeing its inadequacy, proposed increasing the draught to $10\frac{1}{2}$ feet, so that vessels of 800 tons burden could come up to the Pont de la Concorde at Paris at all times, and the execution of a project with this end

in view was decreed in 1878. At the present time, between the first lock at Surenne and the last one at Martot—15½ miles above Rouen—there are seven locks, the average distance between them being 15½ miles. The average rise of these nine locks is 8 feet 3 inches, the maximum at Martot being 13 feet 9 inches, and the minimum at Mericourt 6 feet 5 inches. The estimated cost of the improvements, which are still in progress, consisting principally of several new locks provided with movable weirs, is £1,700,000, including the provision of the same draught of water throughout the whole of Paris. At Bougival, 30 miles from Paris, the new lock is 722 feet long, and at Port Villez, 60 miles from Paris, the lock and weir, which together cost £235,000, were completed in 1880. The weir of this lock consists of two navigable passes 198 and 194 feet wide, and of an overfall 267 feet wide. Many interesting details concerning fixed and movable weirs in France will be found in Mr. Vernon-Harcourt's Paper on that subject.

The navigation of the Seine from Rouen to the sea (76 miles) is both tedious and difficult, owing to its very sinuous course and to the numerous shoals which obstruct the shifting channel of its estuary, and it is with the view of rectifying this latter evil that a canal is now being made between Tankerville and Havre, so that ultimately vessels navigating the Seine above Rouen may reach Havre with expedition and at small cost. The canal will be at one level throughout, and is to have a lock at each end 590 feet long and 98 feet wide. The depth of the canal will be 10½ feet (3.25 metres).

With regard to traffic on the Seine, it was stated in 1872 by Mr. Krantz that the canalized river between Paris and Rouen carried 150,000,000 ton-miles, or more than one-eighth at that time of the whole water traffic of France, and about one-twenty-fifth of that of all the railways.

The mean discharge of the Seine is 24,500 cubic feet per second from a total area of 30,000 square miles. The discharge at Paris at high floods is 60,000 cubic feet per second, and 1,230 cubic feet at extreme low water. During the extraordinary high flood of 1876 the water rose 25 feet 3 inches at Paris, and 13 feet 6 inches at Rouen.

The Loire rises in the Cévennes 30 miles from the course of the Rhone, and flows in a north-west and west direction through the centre of France to the Bay of Biscay. The mean discharge of the Loire is 34,800 cubic feet per second from an area of 44,000 square miles. Of its total length of 607 miles, 450 are navigable, but its chief tributaries, four on the left and one on the right bank, are of little service to the navigation, owing to their shallow and irregular channels. In the middle part of its course the Loire traverses some of the most beautful scenery in France. In the lower part, which is subject to frequent and sometimes disastrous inundations, high embankments have been thrown up to contain the floods, and a lateral canal was completed in 1838 between Roanne and St. Brisson to afford the means of navigation at all stages of the river. Of all French rivers the Loire is the most irregular in its *régime*, and therefore the most intractable as a navigable stream. Its bed, occasionally half filled for a day or two with sand-banks, intersected by serpentine channels, which are barely navigable for small river craft, becomes covered in a few days with from 20 to 24 feet of water. At such times the embankments are overtopped, many breaches are made in them, and the country is inundated far and wide. To give an idea of the great variations in the volume of water discharged by the Loire below the confluence of its chief tributary the Allier, I may state that, according to Mr. Reclus —to whom I am indebted for many of my figures concerning French rivers—the maximum discharge at floods is 353,000 cubic feet per second, and the minimum only 1,060; the mean being 10,600 cubic feet per second. Thus the extreme difference in the discharge of the Loire at the "bec d'allier" is from 1 to 330, or more than one-half greater than that of the river Ruhr, which, as has been already mentioned, is from 1 to 200.* The City of Nantes is the chief maritime port of the Loire, but owing to its shallowness

* Régime of the Lower Loire, after Comoy, 1856, in cubic feet per second:
Confluence of the Maine maximum discharge 215,145; minimum 4,485=1 to 47
Nantes maximum discharge, 215,980; minimum, 10,600=1 to 20

ocean steamers of deep draught are compelled to load and unload 30 miles lower down stream, either at St. Nazaire or at Paimbœuf, close to the river mouth.

The Garonne (615 miles in length) rises in the Pyrenees within the Spanish frontier, becomes navigable at Cazéres, is connected with the Mediterranean at Toulouse by a canal, and finally unites with the Dordogne about 13 miles below Bordeaux to form the large estuary of the Gironde, a tidal basin 50 miles long. The river frequently overflows its banks, and, owing to general shallowness and frequent changes in its bed, the inland navigation of the Garonne, and of its tributaries above Bordeaux, is subject to many difficulties, in spite of the generally successful results of the system of training works that has been adopted at several places, with the object of maintaining a depth of at least 7 feet in the artificially contracted channel without having recourse to dredging.

Vessels of 800 tons can trade to Bordeaux, but ships of larger burden can only ascend the Gironde as far as Pauillac on the left bank, about 30 miles below Bordeaux, and about the same distance from the Atlantic. The Gironde, which comprises the united waters of the Garonne and Dordogne, has a mean discharge of 41,000 cubic feet per second from an area of 35,000 square miles.

The Rhone (635 miles in length) has its source in Switzerland, not far from the St. Gothard Pass, and enters France by the narrow defile of l'Écluse. Its upper course is both rapid and tortuous, and hardly navigable, until Lyons is reached at the confluence of the Saône. The Saône from its course in the Vosges flows south-west and south, and possesses an excellent system of navigation for 170 miles, through the lower part of its highly fertile valley. The chief towns on its banks are Beaune, a little above which the Saône and the Seine are connected by the Canal of Bourgogne-Chalon, where the Canal du Centre joins the Saône with the Loire and Mâcon. In the 200 miles from Lyons to the Mediterranean the Rhone falls 532 feet, giving an average of 32 inches to the mile. Notwithstanding this great inclination, the river is navigable the whole way for vessels of considerable burden excepting at extreme low water, when the depth is less than 3 feet in many places, or barely enough for the working of the steam-tugs on the grapping system, which are in constant use above Arles, a large town at the head of the delta, and 175 miles from Lyons. The charge for up river transport between these two places is $\frac{1}{2}d.$ per ton per mile.

The Rhone has a mean discharge into the sea of 60,600 cubic feet per second from an area of 38,000 square miles. Its maximum discharge is 423,840 cubic feet per second, and its minimum 19,426 cubic feet = 1 to 22.

The improvement of the Rhone as far as Arles from the new Mulatière dam (525 feet long and 52½ feet wide) at the junction of the Rhone and the Saône,* so as to ensure everywhere a depth of 5 feet 3 inches (1.60 m.) at low water, is now in progress, and a grant of £1,800,000 has already been obtained for this work. The project is a combination of the two systems of regularization and canalization, and the cost of improving the navigation throughout on this principle is estimated by Mr. Pasqueau, the author of the project, at £2,250,000. Between Arles and the Mediterranean the minimum depth of the channel is about 6 feet, or as much as exists on any one of the bars at the mouth of the river.

To avoid these bars, after having tried unsuccessfully to deepen one of them by the system of parallel piers, which for want of being carried sufficiently far seaward never had a fair chance of success (although such a chance would have been but a feeble one if, as has been stated on good authority, there is no littoral current), the Government resorted to the expedient of cutting a lateral canal 2 miles in length, and furnished with a lock, from the tower of St. Louis to the neighboring Bay of Repose. By means of this work, the annual maintenance of which has not been onerous, vessels drawing up to 19 feet have been able to enter the Rhone since 1862, when the canal was completed at an expense of £620,000 including quays. As a work of art, the canal (which I visited more than once whilst under construction) reflects great credit on Mr. Pascal, Inspector-General

* Relative discharge of the two rivers at their confluence at Lyons, in cubic feet per second—

| | Extreme low water. | Mean. | Extreme floods. | Proportion low to high. |
|---|---|---|---|---|
| Rhone.... | 8,830 .. | 22,958 .. | 211,920 .. | 1 to 24 |
| Saône.... | 2,119 .. | 8,830 .. | 141,280 .. | 1 to 66 |

of Roads and Bridges, under whose direction the works were executed.

With regard to the condition of the Rhone as a navigable stream, Mr. Reclus stated in 1879, that "before the construction of the Lyons and Marseilles Railway, the navigation was very important, but that since that time it has never been able to compete with the railway; in place of sixty-two steamers, which were always employed in carrying goods from one port to another, there are now only eight boats employed in carrying an annual freight of little more than 200,000 tons."

With but few exceptions, the earliest of the canals in France were laid out solely with reference to local interests, and were therefore as a rule, badly adapted for economical transport over very long distances. On the other hand, since 1821–22 when the most important canals of the country were designed, and their execution decreed, French waterways have been dug down to a uniform depth of 5 feet 3 inches (1.60 metre) over a bottom width of 33 feet (10 metres), with the view of giving the cheapest and most direct means of transit between great centres of trade far apart from each other. In the north, the Seine is placed in direct communication with Belgium, by the river Oise which the canal of St. Quentin prolongs to Mons, and the canal of Charleroi to the town of that name. On the other hand, the canal of Ardennes unites the basin of the Seine with that of the Meuse, and consequently again puts it in communication with Belgium and Holland. In the west, a network of canals, commencing at Nantes, puts Brittany in direct intercourse with the naval ports of Brest and L'Orient; and, by the Loire, with the centre of France. In the East, Paris is in direct communication with Nancy and Strasburg by the Marne and Rhine Canals. In the south, the lateral canal of the Garonne and the Canal du Midi unite the Atlantic with the Mediterranean and Bordeaux with Cette. This latter port is also in direct communication with the Rhone by means of canals to Aigues Mortes, and Beaucaire.

The celebrated canal of Languedoc, now an integral part of the Canal du Midi, was built in 1667–81 (eighty years before the opening of Brindley's Bridgewater Canal) by Riquet, the greatest engineer of his day. It has a length of 171 miles and a depth of 5 feet 3 inches, and its highest part is 600 feet above the sea. From this summit level it communicates with the Garonne, and therefore with the Atlantic, by twenty-six locks, and descends the southern slope by seventy-three locks to the Mediterranean.

With reference to the Canal du Midi, I have the authority of Mr. Malézieux, Inspector-General of Roads and Bridges, for stating that, like all the canals in France classed as principal lines of communication by the law of 1879, it is to be deepened to 7 feet 4 inches (2.20 metres) or its level is to be raised in such a way that vessels drawing 6 feet 6 inches (2 metres) may be able to navigate through it without delay. The same decree also prescribes that the locks of all the principal canals shall have a clear length of 126 feet (38.50 metres) and a width of 17 feet (5.20 metres) with sufficient water on their sills (now fixed at 2.50 metres) to allow the free passage of vessels drawing 6 feet 6 inches (2 metres).

According to the returns of Mr. Krantz, member of the National Assembly for inquiring into Internal Navigation in 1872, the length, cost of construction, and of transport were then as follows:—

Total length 8,120 miles, of which 3,123 miles were canals, and 4,997 rivers.*

Cost of construction £46,295,857, of which £32,738,715 for canals, and £13,557,152 for rivers.

Cost of transport with tolls, 0.324*d.* per ton per mile for canals, and 0.420*d.* for rivers.

Ibid., without tolls, 0.243*d.* per ton per mile for canals, and 0.324*d.* for rivers.

To complete Mr. Krantz's information and to bring the mileage of French waterways, already made and still to make, down to a later date, I quote the following from a tabular statment by Mr. Conder.

| | Miles open in 1878. | Miles to open. |
|---|---|---|
| Basin of the Seine | 1,582 | 233 |
| " Rhone | 994 | 201 |
| " Loire | 1,979 | 774 |
| " Garonne | 1,324 | 328 |
| " Gulf of Gascony. | 272 | 162 |
| Channel and North Sea | 576 | 59 |
| Charente and Sèvre Niortaise. | 342 | 56 |
| Total open and to open | 7,069 | 1,813 |

Grand total, 8,882 miles.

Total cost of 7,039 miles of waterways, £43,608,516.

* Mr. Krantz remarks that "the 'rivers' include [illegible]

From the foregoing, it would appear that in 1878 France had spent considerably more than double the sum spent by the United Kingdom (£19,145,866) up to 1844 in the improvement of inland navigations. Nevertheless, comparatively large as had been her expenditure in this regard up to 1878, a Bill was deposited in that year in the Chamber of Deputies for still further systematizing and improving the internal navigation at an estimated cost of £40,000,000.

From the "Bulletin des Travaux Publics, 1881," an interesting comparison has been made by Mr. Petit, concerning the three great trade routes in France. Mr. Petit's résumé is as follows:—

| Transit Routes. | Length. | Tonnage. | | Proportion of Tonnage. |
|---|---|---|---|---|
| | | Mean. | Kilometric. | |
| | Kilometres. (Miles.) | | | Kilo. |
| Railways | 24,383 (15,141) | 415,394 | 10,801,259,457 | 75 |
| Navigable rivers | 11,986 (7,432) | 182,000 | 2,174,531,000 | 15 |
| Highways | 37,462 (23,264) | 39,400 | 1,480,148,000 | 10 |
| Total | 37,813 (45,827) | 196,000 | 14,455,938,457 | 100 |

This Table shows that although in 1880 the length of inland navigations was one-half that of railways, the amount of traffic carried by them was only one-fifth. On the other hand, taking the cost of railways at £30,000 per mile, and £6,000 as that of canals as capital, and the figures 415,394 and 182,000 in the above Table as representing traffic, the contrast is evidently and strikingly in favor of canals even in their unimproved state.

The total length of French railways in 1884 was 16,886 miles, as compared with 5,262 miles in 1860, being an increase of 320 per cent. in the last twenty-four years.

SPAIN AND PORTUGAL.

The chief rivers of the Iberian Peninsula are eight in number. Five of them, the Minho, Douro, Tagus, Guadiana, and Guadalquiver, drain the western valleys, and flow into the Atlantic; and the other three, the Ebro, Jucar, and Segura, drain the eastern valleys, and discharge their waters into the Mediterranean. The high mountain ridges and elevated plateaux which Spanish rivers have to descend give them a rapid course, so that in general they are of comparatively little use for navigable purposes, and running, as they often do, in very deep beds, are frequently unavailable for purposes of irrigation.

The Tagus drains an area of 37,500 square miles. Taking its rise on the borders of Aragon and Castille, it dashes down to the plain of Zarita, and thence, flowing tranquilly through the Royal Gardens at Aranjuez, at an elevation of 1,700 feet above the sea, passes with quickened velocity the old walls of Toledo, Talavera, Alcantara, and Abrantes, and finally, after a course of 570 miles from its source, empties itself into the Atlantic, about 7 miles below Lisbon. Unfortunately for commerce, the Tagus is only navigable to the Portuguese frontier, or about 120 miles from the sea. Opposite Lisbon, on the south shore, is Cassilhas Point, or the eastern extremity of what may be called the Port of Lisbon, whence a wide expanse towards the north opens out into a magnificent harbor, of from 2 to 7 miles in breadth. At the Point itself the river is 1 mile wide, but it narrows to ¾ mile at Belem, on the north bank 2 miles below Lisbon, whence it expands again to a width of nearly 2 miles at its mouth. The bar has a depth of from 6 to 7 fathoms at low water of spring

this statement are not all strictly navigable, and that the length of those portions which are suitable for navigation does not exceed 5,700 kilometres" (3,524 miles).

tides, and the channel within it soon deepens to 19 fathoms. Notwithstanding this great depth, however, the bar is impracticable in south-westerly gales, and in winter, or when the freshets are strong and accompanied with westerly gales, continues so for several days together.

The Douro is 485 miles long, and drains an area of 37,000 square miles. Its direction is generally west, and it traverses the most mountainous portions of Leon and Salamanca before it reaches the Portuguese frontier. Thence to the sea, the channel is everywhere narrow, with a rocky bed, and the water, being confined, the current frequently exceeds 9 miles an hour at times of thaw and heavy rains. Instances have already been given of great oscillations in the volume of discharge in the rivers Ruhr and Loire, but these may be termed insignificant when compared with the variations in the volume of the Douro. On one occasion, in 1860, when the river rose to the level of 33 feet 9 inches above low water of spring tides at the suspension bridge, 3½ miles from the sea, the velocity equalled 16 knots an hour, and the discharge 995,000 cubic feet per second, or two and a half times as great as the highest flood-discharge of the Tagus. At the same bridge, and according to the same authority, Mr. A. J. Nogueira Soares, the lowest discharge in the summer months of 1875 was only 700 cubic feet per second.

Mr. Soares, in stating these phenomena, is justified, therefore, in declaring that there is probably no other river of importance where so great a flood-rise takes place so near the sea, or where the volume of fresh-water discharge varies from 1 to 1,500. During spring tides, he adds, the total tidal outflow does not exceed 35,300 cubic feet per second, or about one-thirtieth part of a great river flood.

The depth of water on the bar of the Douro, between the years 1874–78, averaged 14 feet 6 inches at low water, or 25 feet 6 inches at high water of spring tides. Oporto, the second city of Portugal, stands on the side of a steep eminence of about 200 feet elevation, which rises from the north bank of the Douro about 2 miles from the sea. The river is navigable for 70 miles from the entrance, and boats of light draught can proceed 30 miles higher. Grain and other produce are floated down from Spain on flats, but navigation is often interrupted by heavy floods.

Guadalquiver rises on the borders of Murcia, drains 22,000 square miles, has a length of 375 miles, and occupies the centre of the plain that lies between the Sierra Morena and the chain of Granada. In the upper part of its course it intersects the rich province of Andalusia, and after pursuing its way through pestiferous swamps to Cordova and Seville at last forms a harbor near its mouth, above the seaport of San Luca de Barrameda, whence Columbus sailed on his third voyage to America in 1498, and Magellan on the first voyage of the circumnavigation of the world in 1519. The Guadalquiver is navigable for vessels of 100 tons at certain seasons of the year, up to Seville, 70 miles from the sea, but, as a rule, vessels of more than 10 feet draught are obliged to load and unload about 8 miles below the city. The channels between the shoals at the mouth of the river are only practicable for small vessels.

The Guadiana rises in La Mancha, and after passing through the province of that name, flows on to Merida and Badajos. A little below the latter it turns to the south and enters Portugal, through which it flows for nearly 100 miles, and then, again washing the frontier of Spain, forms the boundary of the two kingdoms to the sea. The area of the basins of the Guadiana is 25,000 square miles. Although 316 miles in length, the river is only navigable up to the town of Mertola, about 40 miles from its mouth at Villa Real. The entrance to the Guadiana is encumbered with shoals, and at low water there is only a depth of about 6 feet on the bar, or 18 feet at spring tides. Within the bar, however, off Villa Real, where the river is ½ mile broad, the depth is 27 feet.

The Ebro rises in the province of Santander, and drains 39,000 square miles, and after a course of about 470 miles, empties itself in the Mediterranean, about 15 miles east of the town of San Carlos de la Rapita. It receives one hundred and fifty tributaries, and its chief towns are Tudela, Saragossa, and Tortosa. At Amposta, 20 miles below Tortosa, the river divides and runs into the sea by two branches. In order to facilitate the

communication with the sea, a lateral canal, 10 miles long and 5 feet deep, runs south from Amposta to San Carlos, at Port Alfaques, where there is room for a large number of vessels not drawing more than 18 feet. The principal commercial utility of the Ebro is the transport of grain from Saragossa to Tortosa, together with the floating down of timber from the Pyrenees. Owing to the shallow channels of the Delta, however, and to the numerous sandbanks at its mouths, only vessels of very light draught are able to pass the bars, and hence the navigation of the Ebro, although the largest river in the peninsula, is not very important. As a source of supply for irrigation, however, the Ebro, like the majority of Spanish rivers, is of more value in this respect than as a navigable stream. Its bed is rocky, and its current above the influx of the Segre, its principal affluent on the left, much disturbed by rapids and cataracts: and though this evil has been remedied in part by the construction of a navigable channel, the Imperial Canal from Tudela to a point 20 miles below Saragossa, yet the obstacles to navigation are still great; and whilst its use as a source of supply for irrigation is increasing, its volume for navigable purposes goes on decreasing in the same degree.

Besides the navigable canals connected with the Ebro, there are only worthy of special mention the canal of Segovia, connecting that town with the river of the same name, and the canal of Castille, to unite Santander with the Douro, a work, however, which is only partly finished. According to Millet, the total length of navigable canals in Spain was only 130 miles in 1875. On the other hand, the length of her railways was 5,600 miles in 1884.

### ITALY.

Italy is not rich in waterways except in the valley of the Po. The navigable portions of her rivers—the most important of which will shortly be described—have only an aggregate length of 1,100 miles.

The Po rises at 6,560 feet above the sea, and in a course of 350 miles drains an area of 29,000 square miles. At a distance of 20 miles from its source it enters the plain of Saluzzo, between which and Turin, a distance of only 30 miles, it receives three considerable tributaries. The Dora, which flows past Susa at the foot of Mont Cenis, unites with the greater river a little below Turin, and the Sesia joins it 25 miles below the confluence of the Dora. About 30 miles still further on, the Po is joined by the Ticino, which brings with it the overflow of Lake Maggiore. Its next great affluent is the Adda, which flows through Lake Como; then comes the Oglio from Lake Iseo; and finally the Mincio runs in near Mantua from Lake Garda. At its confluence with the Mincio, the Po has a width of from 1,200 to 1,800 feet, and it then continues to flow on in an undivided stream to its first bifurcation near Ponte Lagoscuro, and thence on to Maria de Ariano—about 25 miles from the sea—where it parts into two arms, and these again are subdivided into several other branches, forming an extensive delta about 20 miles in width from north to south. The growth of the delta since the time of the Romans is very marked. The town of Adria, which was then a maritime town, now stands on the banks of the Po 20 miles inland, and it has been estimated that from the year 1600 to 1800, the delta advanced at the rate of 225 feet annually. On the other hand, to the north of the delta, there is equally good evidence of the encroachment of the sea on the land.

The Po is continuously embanked from near Cremona to the marshes at its mouths. At its highest flood the water rises 24 feet above extreme low water at the confluence of the Ticino; 26 feet near Piacenza; 20 feet at Cremona; and 28 feet at Ponte Lagoscuro, 4 miles above Ferrara, where the level of low water is only 9 feet above the sea, from which the old city is now removed 50 miles, or 20 miles further from the coast than two thousand years ago. Hence it is that the top of the embankments at Ferrara is higher than the roofs of the houses. The prevention of the lateral spread of the water in floods by dykes is said by many engineers to occasion the deposit of sediment in the channel, and consequently to cause an elevation of the bed, which requires the embankments to be raised proportionally; but Lombardini has shown that the effect of this on the Po is by no means so considerable as has been

often represented, and that in the middle lower course of the river the bed of the proper low-water channel is subject to so little permanent change of level as to have now become substantially constant.

The mean discharge of the Po is 60,745 cubic feet per second, its maximum 181,580, and its minimum 7,558 cubic feet per second, or a ratio of 1 to 24. The waters of the Po are very heavily charged with detritus, and according to Mr. Boccardo, the volume held in suspension is at times $\frac{1}{30}$ of the volume of water discharged.

The Po is navigable from its mouth for vessels of 130 tons up to Valenza, 600 feet above the level of the sea, and 7 miles below the confluence of the Sesia, and below the confluence of the Oglio the depth of the main river at extreme low water is never less than 5 feet 10 inches; but as most of the transport which would otherwise be carried on by means of its channel is now effected by railways, of which Italy possessed 5,651 miles in 1883, the river has lost much of its relative importance as a route for commercial communication.

The Adige rises in the Tyrolean Alps, and drains 5,400 square miles in a length of 234 miles. Flowing southward it passes by Trent, and enters Lombardy. After passing Verona, it flows nearly south-east, and pursues a course parallel to that of the Po till it enters the Adriatic by an independent mouth about 13 miles north-east of Adria. The waters of the two rivers have been made to communicate by artificial cuts at several places. The Adige is navigable from its mouth to Trent, but the velocity of the current impedes the navigation.

The Tiber rises in the Apennines at a height of 3,805 feet above the sea, and drains 6,500 square miles, and after a course of 240 miles, generally in a south direction, empties itself into the Mediterranean through two mouths about 16 miles south-west of Rome or 24 miles by the course of the river. The mean discharge of the Tiber is 10,800 cubic feet per second, and its minimum discharge 5,800 cubic feet per second.*

* The proportion of the minimum to the maximum flood has been variously estimated by Italian engineers as being from 1 to 25 to 1 to 30; or from a minimum discharge of 3,500 cubic feet per second to a maximum of 105,000 cubic feet. According to Mr. Vescovali, the discharge of the Tiber has never been less than from 5,600 to 6,300 cubic feet per second.

Rozet has calculated that the advance of the delta for many centuries past has kept steadily at the rate of 13 feet per year. The estuary, which originally formed the harbor of Rome, was so reduced in depth by silt from the river and sand rolled in by the sea, that it was found necessary in the days of the Empire to cut a channel from a point about 1½ mile above Ostia (the ancient sea-port of Rome, and now 2½ miles inland) to the coast, at a place called Fiumicino, situated at 2 miles N. of the chief disemboguement of the Tiber, now called the Bocca di Fiumara. The artificial canal—known as the Fiumicino branch—(on the north bank of which are the remains of the once famous ports of Claudius and Trajan) is still the only navigable channel between the Mediterranean and Rome, the old Fiumara mouth being obstructed by constantly-shifting sandbanks.

The rise of the Tiber in its great floods is very considerable, and is measured from the zero of the hydrometer at the Ripetta stairs at Rome. This zero is 4 feet above the level of the sea. The lowest known surface of the Tiber at the stairs is 17½ feet above zero, and its mean height 22 feet. In the inundation of 1870 when I was on a visit to Rome, the waters rose to 56 feet 6 inches above zero, and as the pavement of the Ripetta and that of the adjacent streets is only about 44 feet above zero, all the north-west quarter of the city, including the Corso and other important business streets, was overflowed, to a depth near the river of about 12½ feet, and the direct and indirect damage occasioned by the flood, which was the greatest on record since 1637, could hardly be over-estimated. Numerous schemes have since been proposed to prevent the recurrence of a similar disaster. Grave objections have been made to many of these projects, but on one point all engineers seem to agree—and this principle is now being practically carried out—the expediency of widening and straightening the channel at various points within and near the limits of the city, of carefully regulating the outflow of drains into the river, and of removing from its bed the numerous artificial obstructions, chiefly piers of old bridges, and accumulated rubbish of centuries.

The Tiber is navigable from the sea to

Rome for vessels of 140 tons, and, with some difficulty, 60 to 70 miles further for vessels of 60 tons. At the Fiumicino mouth of the river the entrance is narrowed between parallel piers so as to increase the scour over the bar, but the available depth on it is rarely more than from 6 to 8 feet.

The Italians were the first people in Modern Europe who attempted to plan and execute canals. As a rule, however, they have been principally undertaken for the purpose of irrigation. The total length of the navigable canals is 435 miles. The most important are the Canal Cavour, in Piedmont, which, supplied from the Po, begins at Chivasso and terminates at Turbiga, a distance of 52 miles; the Grand Canal, in Lombardy, supplied from the Ticino, near Tornaveuto; the Canal of Pavia, also supplied from the Ticino, and passing through Binasco; the Canal of Martesana, which, from Milan through Gorgonzola, leads to Cassano on the Adda. The provinces of Polesina in Venice, of Padua, and the Emilia have all excellent canal systems. In Tuscany the most important are those of Pescia, Pisa, and Ombrone.

### AUSTRIA-HUNGARY.

As the highlands of Austria form part of the great watershed of Europe which divides the waters flowing north into the North Sea or Baltic, from those running south or east into the Mediterranean or the Black Sea, all Austrian rivers of note flow either north, south or east. All her great river mouths, moreover, are situated in other countries, and one of them, the Danube, has its source as well in a neighboring State. The courses of its chief streams, namely the Dnieper, the Vistula, the Oder, and the Elbe, have already been summarily passed in review, and it therefore only now remains for me to describe the course of the Danube to complete the list.

### THE DANUBE.

The Danube is the largest river in Europe as regards volume of discharge, but is inferior to the Volga in the length of its course and the area of its basin. It rises in the Black Forest at an elevation of about 3,600 feet above the sea, and drains 316,000 square miles, its total length being 1,750 miles.

From the mouth of the Iller, which divides Würtemburg and Bavaria, the Danube is fed by at least three hundred tributaries. On the right bank, the chief of these, with their drainage area in square miles, are: the Inn (9,600), the Drave (14,300), and the Save (37,500), and on the left bank the Theiss (60,000), the Olta (9,000), the Sereth (18,000), and the Pruth (10,000). Together, these seven streams have a length of 2,900 miles and drain one-half of the whole extent of the Danube basin.

### UPPER AND MIDDLE DANUBE.

The upper part of the river first becomes navigable, for flat bottomed boats carrying 100 tons, at Ulm, 130 miles from its source, and only a few miles below the confluence of the Iller, its first tributary of any importance.

At Kelheim, half way between Ulm and Passau, the Danube communicates with the Rhine by means of the Ludwig Canal, and the rivers Altmühl, Regnitz and Main. The canal is 110 miles long and 7 feet deep, and was completed in 1844 by King Ludwig the First of Bavaria. From Ulm to Passau (220 miles), at the mouth of the river Inn, which doubles the volume of the main stream, the Danube traverses the great Bavarian plain, but thenceforward it flows through a mountainous region till it reaches Vienna. In this distance of 406 miles of the lower section of the Upper Danube the river has been considerably improved by works of correction, and vessels drawing 4 feet can now navigate the whole distance at low water, excepting at the Fischament-Theben rapids, where the depth is occasionally reduced to 3 feet.

At Vienna, which is situated on the right and left banks of a branch of the Danube (164 feet wide and 4 feet deep at low water) at an elevation of about 520 feet above the sea, and at a distance of 1,208 miles from the Sulina mouth, the main stream of the river has been brought 1½ mile nearer to the city by a new channel 10 miles long, 1000 feet wide and with a depth of from 10 to 12 feet below ordinary low-water level. This great cut involved the removal of 12,000.000 cubic metres of sand and gravel, and, with all its subsidiary work, cost £3,250,000. The enterprise was established by an Imperial Commission in 1866, and the

proposal to construct the regulation on its present plan had the able support of Mr. James Abernethy, Past-President Inst. C.E.

The cutting has been very successfully carried out, and has already been of great service, not only in protecting Vienna from disastrous floods, the principal object of the scheme, but in improving the railway communications and the navigable capabilities of the river at this portion of its course.

Further particulars of this interesting river diversion, written by the Engineer-in-Chief, Herr Von Wex, are published in our Abstracts of Papers in Foreign Transactions.

The construction of a deep canal, about 150 miles long, from a point on the left bank about 6 miles below Vienna, to Oderburg on the river Oder, has lately been under serious consideration, and the execution of this project bids fair to become an accomplished fact at no distant day.

From Vienna the Danube flows east for 150 miles through a wide expanse of plain country to Waitzen; and then turning south pursues that direction through the great plain of Hungary by numerous windings to Esseg situated at the confluence of the Drave, 347 miles below Vienna, and 165 miles below Buda Pesth. This imposing-looking capital of Hungary is situated on the right and left banks of the Danube at 182 miles below Vienna, 152 below the confluence of the March at Theben, the frontier of Austria-Hungary on the left bank; 146 from Pressburg; 89 from Gönyö near the confluence of the Raab; and 21 from Waitzen. From Esseg the river trends south-east to Semlin (140 miles), the lower frontier town of Hungary on the right bank at the confluence of the Save, and immediately opposite Belgrade, the capital of Servia. Hence to Old Moldova (76 miles), and then on to the Hungarian-Roumanian frontier at Old Orsova (63 miles) the river flows nearly due east. At Old Moldova, it enters a series of rocky gorges, unequalled in Europe for their grandeur; and after sweeping through a succession of deep pools and shallow rapids, confined within the grand passes of Stenka, Izlaz, and the Kasan, finally reaches its last and most formidable rapid called the "Iron Gates," 632 miles from Vienna, and 582 miles from the Black Sea.

Although the Danube, from Vienna to Old Moldova, has also been regulated in numerous places and at great cost, by narrowing and training works, consisting of groynes, dams, and longitudinal dykes, there has been but little appreciable improvement effected in its general navigable depth. On this account, projects, having in view the permanent acquisition of a sufficiently wide channel of from 6 to 8 feet deep at every point between Passau and Old Moldova, have lately been prepared by Government Engineers, which involve an outlay of £2,000,000 to effect the desired improvements, the principal of which would be the permanent removal of the Fischament-Theben, and the Pressburg-Gönyö shoals.

With the exception of a short stretch of the river near Gonyo, the existing channel between Vienna and Old Moldova, affords a minimum depth of from 4 to 5 feet, during nearly two-thirds of the year (taking the ice into consideration); but at Gonyo itself, the navigation during the dry season is so difficult that a depth of from 3 to 5 feet is only maintained by Mr. Murray Jackson's excellent system of steam-raking, a full account of which will be found in our Minutes of Proceedings.

The Danube between Old Moldova and the Iron Gates (69 miles), 6 miles below Orsova, the frontier town of Hungary, is traversed at eight different places by reefs of sharp-pointed rocks, which render the navigation difficult at ordinary low water, and altogether impracticable at the lowest water season. These serious natural obstructions have hitherto been the great barrier to the free development of traffic on the middle and lower Danube, and the existing slackness of trade at this part of the river will continue, and possibly increase, until its navigable condition has been radically improved. These so-called Cataracts of the Iron Gates, which are wholly within the territories of Roumania and Servia, have a length of 5,070 feet, with inclinations of 1 in 507 at high, and 1 in 307 at low, water; the extreme variations between high and low water being 14 feet 6 inches at the head and 22 feet 6 inches at the foot of the falls. The level of low water at Old Moldova is 201 feet, and at the foot of the Iron Gates,

118 feet above sea-level. This fall of 83 feet in 69 miles gives an inclination of 1 in 4,400, as compared with 1 in 2,220 between Passau and Vienna, and of 1 in 10,000 between Vienna and Old Moldova.

For more than a quarter of a century projects have been made for surmounting the difficulties between Old Moldova and the foot of the Iron Gates, by four different systems of treatment, namely, by open cuts; by simply narrowing the channel; by excavated channels confined within submerged and insubmergible walls; and by a combination of one or more of these plans, aided by one or more lateral canals.

The latest project is that of an International Commission of Engineers named by the Austro-Hungarian Government in 1879. This Commission proposed to establish a channel 2 metres deep at extreme low water, at every point between Old Moldova and Turn-Severin by means of cutting 60 metres wide through the upper seven shoals, and to construct a lateral canal at the Iron Gates on the Servian shore, provided with two lift locks (508 feet by 118 feet) to overcome a difference of level of 14 feet 6 inches at that place. The cost of the open cuttings was estimated at £350,000; the improvement of the Iron Gates at £530,000.

The width of the Danube between Vienna and Basias (15 miles above Old Moldova) varies from 2,000 to 6,000 feet at low water, and from 7 miles to 30 miles at high water; but to this statement exception should be made of Peterwardein (50 miles above Belgrade), where the entire volume of the river, at high and low water, flows through a channel 40 feet deep, and only 800 feet in width. At this spot, 777 miles from the Black Sea, the Danube is crossed for the last time by a railway bridge, or, indeed, by a bridge of any kind whatever. At the Kasan, a pass 5½ miles long, where the granite cliffs rise to a perpendicular height of nearly 1,000 feet, and where the depth is 80 feet in the dry season, the main width of the river is but 600 feet, and the difference between extreme high and low-water level as much as 23 feet. The mean velocity of the current from Vienna to Basias is 2 knots an hour, and 3 knots at high water, but at the narrow defiles of the Kasan and Izlas it attains 8 knots at high floods.

The Hungarian central section of the river is fed by the Drave, the Theiss, and the Save.

With regard to the Save and the Drave, I have only time to remark that their improvement has never yet been attempted; that the former is navigable in its natural state to the confluence of the Mur (150 miles), and the latter to Sissek (370 miles), and that their lengths from their sources in Illyria to Esseg and Belgrade are 434 and 535 miles respectively.

The Theiss, or Tisza, falls into the Danube on the left bank, between Peterwardein and the confluence of the Save, and is navigable for a length of 475 miles to Tokay. It would require the time allotted for a whole lecture to give anything like a detailed description of this remarkable affluent, and therefore, in the few minutes at my disposal, I can only sketch its chief characteristics in the briefest possible manner. It rises in the Carpathians, and its basin drains one-fifth of the great valley of the Danube. Half a century ago it had a total course of 828 miles, and from Tisza Uylek, where it ceases to be a mountain stream, and enters the great Hungarian plain, a course of 750 miles. The length of its valley from Tisza Uylek is only 372 miles, so that, like the lower Seine, its length was double that of the plain through which it flowed. From Tisza Uylek to Szegedin (621 miles) the fall was 136 feet in 621 miles, or 1 in 24,500; and from Szegedin to the mouth of the river, 129 miles, only 8 feet, or 1 in 73,000. Between 1832 and 1879 the cut-offs executed by the Government for the principal purpose of protecting the adjacent lands from inundations, were one hundred and thirteen in number, of an aggregate length of 83 miles. These cuts shortened the river 300 miles below Tisza Uylek, and cost £690,000, exclusive of a further sum of £2,000,000, which was spent by local companies on 1,000 miles of embankments. According to the report of Mr. Herrich, Ministerial Councillor, the result of these great works has been to protect an area of 4,200 square miles, out of a total area of 6,000 square miles of low ground, from floods; but from no authority can I glean any information concerning the effect of the cut-offs on the navigable condition of the

river. Unfortunately, however, one fact is but too well known, namely, the great disaster of 1879, when the large town of Szegedin, at the confluence of the river Maros, was almost totally destroyed, and many of its inhabitants swept away by an unprecedentedly heavy flood. It should be added that the Maros enters the Theiss at a bad angle, and has also been greatly reduced in length—from 430 miles to its present length of only 162 miles.

The two chief canals in Hungary are the Bega, 75 miles long, joining Temesvar with the Theiss at Tetel, a little above its junction with the Danube, and the Frans Josef, 69 miles long, which stretches from the Danube at Battina by Zombor to the Theiss near Foldvar. On the latter canal the traffic increased from 246,000 ton-miles in 1876 to 600,000 ton-miles in 1878, but it has never yet, I learn, paid any interest to its shareholders.

According to Mr. Lanfranconi, whose Papers on Hungarian rivers, with excellent maps thereof, may be referred to with advantage in our library, Austria-Hungary possesses 2,104 miles of waterways made up as follows:

| | Miles. |
|---|---|
| Passau to Orsova | 817 |
| Drave, Theiss and Save | 1,013 |
| Raab and Inn | 48 |
| Canals | 226 |
| | 2,104* |

Traffic on the upper and lower Danube is mostly carried in barges belonging to the Imperial and Royal Danube Steam Navigation Company, of which they possess about eight hundred, the greater portion having a carrying power of 250 tons. The mean annual traffic up-stream from Belgrade to Pesth is 600,000 tons, or about as much as by rail. The barges have been built in recent years entirely of steel, and have generally a length of 180 to 190 feet, with 24 feet beam and 8½ feet depth, and their displacement is 120 tons without cargo. The largest steamers are from 220 to 250 feet in length, with from 25 to 27½ feet beam and 10 feet deep at the sides, with a slight displacement of 440 to 460 tons.

Haulage is performed on the upper and central Danube by steam-tugs and chain-tugs; and it was with the view of obtaining some authentic information on this important subject that I applied some time ago to Mr. Murray Jackson, late Chief Engineer of the Danube Steam Navigation Company, for a short statement of the result of his long and varied experience regarding the relative merits of each mode of traction. Mr. Jackson has obligingly furnished me with some valuable "Notes" on "Water Traction by Steam Power," which are too long to repeat at this advanced hour; but I trust the Council will permit them to appear hereafter in the shape of an Appendix to my lecture, should the latter be considered worthy of publication.

* The total length of railways open for traffic in Austria-Hungary in January, 1884, was 12,223 miles.

### LOWER DANUBE.

The Lower Danube begins at the foot of the Iron Gates, and terminates in the Black Sea, from which it is distant 340 miles in a straight line,, and 580 by the windings of the river. The left bank from Verciorova, the Roumanian frontier town (2½ miles from the Hungarian frontier town of Orsova) to mid-channel of the Pruth (11 miles below Galatz), is Roumanian territory; and from mid-channel of the Danube, opposite the mouth of the Pruth, the frontier of Roumania is conterminous with that of Russia (according to the Treaty of Berlin of 1878) to mid-channel of the Danube at Ismail Chatal, and thence to mid-channel of the Kilia branch at Wilkov, where the Kilia branch spreads out into several subsidiary channels. From the village of Wilkov the frontier follows the mid-channel of the Stary Stamboul, the most southerly of the branches of the Kilia delta, till it reaches the sea, at a distance of about 10 miles north of Sulina. The right bank of the river from the confluence of the Save at Belgrade to the mouth of the Timok at Rakovitza (59 miles below the Iron Gates) is in Servia; from Raovitzak to Silistria (284 miles) it is in Bulgaria, and thence to the sea, following the St. George's branch, in Roumania. Thus, both banks below Silistria belong to the Roumanians, with the exception of the left bank from the mouth of the Pruth to Wilkov, and thence to the sea by the Stary Stamboul branch. The fall of the river from the Iron Gates to Sulina gradually becomes less, as in the lower part of all large rivers flowing through their own alluvium as it reaches

the sea. Thus, between the Iron Gates and Tchernavoda, 388 miles, with a difference of level of 103 feet 6 inches, the inclination is 1 in 19,800; between Tchernavoda and Ibraila, 76 miles, with a difference of 11 feet, 1 in 36,500; whilst between Ibraila and Sulina, 116 miles, with a difference of only 3 feet 6 inches, it is reduced to 1 in 175,000.

1. IRON GATES TO IBRAILA.

At the Roumanian town of Turn-Severin, on the left bank, 8 miles below the Iron Gates, are still to be seen, at extreme low water, thirteen of the twenty stone piers of a bridge that was built across the Danube in A. D. 103, by Apollodorus, the architect who built Trajan's column at Rome. The river here is about 3,000 feet wide, and the maximum depth 18 feet. From Turn Severin to Widin, 83 miles, its course is very tortuous, but the general direction is to the south. From Widin, however, to Tchernavoda, 297 miles, its general trend is to the east. The river leaves the mountains behind at Widin, whence to Ibraila, the left bank is everywhere flat and uninteresting. The right bank, on the contrary, is bordered by high banks, as a rule, to the sea, and generally presents a landscape pleasantly varied by headlands, gentle slopes, and cultivated enclosures. Nicopoli, 122 miles below Widin; Sistov, 25 miles below Nicopoli; Rustchuk, 37 miles below Sistov; and Silistria, 68 miles below Rustchuk, all situated on considerable elevations on the right bank, and all famous as great battle-fields between the Russians and Turks, have each corresponding towns on the opposite bank, but the only one worthy of special notice is Giurgevo, the Port of Bucharest, and formerly the *tête du pont* of Rustschuk.

At Tchernavoda, 45 miles below Silistria, the width of the main river is 2,000 feet, and its depth at low water 28 feet. The extreme variation between high and low water is 23 feet, the latter having here a level of 14 feet 6 inches above the sea. When the floods attain a height of 18 feet the whole country is inundated (for the river below the Iron Gates is nowhere embanked), and its width expands across the Balta or island to the village of Fetesci, 8½ miles, to the high left bank of a subsidiary branch of the river, called the Borçea, which, leaving the Danube opposite Silistria, again joins the main stream 31 miles below Tchernavoda. Elaborate competition projects, presented by Belgian, French, German and Swiss engineers, have for some time past been under the consideration of the Roumanian Government for bridging the Borçea at Fetesci, and the main river at Tchernavoda, which was surveyed under my direction in 1882, so as to join Bucharest with Kustendjie, but although two of these projects were considered worthy of high commendation, no decision has yet been come to as to the precise dimensions of the structures to be erected.

The Danube at Tchernavoda, 210 miles from Sulina, is separated from the port of Kustendjie on the Black Sea by an isthmus only 40 miles wide, and if a waterway were cut to that seaport in the line of the existing railway at Trajan's Wall the distance by water from Tchernavoda to Constantinople would be shortened 263 miles; the distance from Sulina to Constantinople being 311 miles, and from Kustendjie to Constantinople only 218 miles. In 1837 surveys were made and a series of levels taken of this part of the Dobruja, with the view of constructing a canal across the isthmus, but the scheme was abandoned on ascertaining that the summit level was 164 ft. above the sea, and that no adequate supply of water could be obtained from the neighboring high lands to fill the locks that would be required to overcome the difficulties of the ground between the river and the sea. In 1854 an English company obtained a concession from the Sublime Porte to construct a railway instead of a canal, and in 1860 the Tchernavoda Kustendjie Railway was open for public traffic. Although well managed, it never prospered, owing to the impossibility of competing successfully with the Sulina route in its improved condition, and in 1882 the line was sold to the Roumanian Government, and it is now worked by the State. It may here be added that in 1884 the length of railways in Roumania already constructed was 850 miles, and the length under construction 340 miles. The charge of the railway for grain discharged from up-river craft at Tchernavoda, then cleaned by machinery and loaded into wagons, and finally shipped at Kustendjie, after

being transported over 40 miles of railway, has generally been 4s. per ton—a charge by no means excessive—and yet, with but very few exceptions, vessels pass Tchernavoda, and go straight on to Ibraila or Sulina; for, in practice, it has been found either more economical or more convenient to take the longer water route. This is another example showing how, in certain cases, preference is given to a very circuitous waterway, instead of to a direct route by land.

On leaving Tchernavoda, the Danube bends to the north and continues that direction to Galatz (13 miles below Ibraila), whence it flows east by south to the sea.

The river between the Iron Gates and Ibraila has frequently a depth of over 40 feet at low water, but at seasons of very low water its bed is encumbered in several places by sand banks, on which the depth is not more than 9 feet, and at 3 shoals, Nicopoli, Sistov, and Tchernavoda, not far below the railway station, the depth is at extreme low water reduced to 7, 6, and 4½ feet respectively. Still the navigability of this long stretch of the Danube, which has never yet been "doctored" by an engineer, may be considered in a good condition compared with other European rivers of anything like the same importance.

Between the Iron Gates and Ibraila, the average width of the main Danube (for *en route* it splits into many branches, forming numerous islands) before it floods its natural banks, is about ½ mile. The extreme difference between high and low water varies from 24 feet 6 inches at Turn-Severin to 23 feet at Nicopoli, and 19 feet 6 inches at Ibraila.

### DANUBE FROM IBRAILA TO THE SEA.

In obedience to the special request of my friend, the President, I shall now inflict upon you *a mauvais quart d'heure* in describing the nature and intention of some of the regulation works which have been carried out under my direction as engineer-in-chief in what may be called the maritime section of the Danube, since the conclusion of the Crimean War—at which epoch the river below Ibraila was in a state of nature, that is to say, unruly and entirely untrained.

From the port of Ibraila, at the head of the maritime section of the Danube, the navigable channel to the Sulina mouth (116 miles) is under the control of the European commission of the Danube. This Commission, by virtue of the Treaty of Paris of 1856, was charged to remove the sand banks which obstructed the navigation between Isaktcha at the head of the delta, and the Black Sea, and authorized to levy tolls on shipping to cover the expenses of the work. Its jurisdiction was extended to Galatz by the Treaty of Berlin of 1878, and further extended to Ibraila by the Conference of London of 1883.

As a "Description of the Delta of the Danube," of "Works executed at the Sulina Mouth," and of "Dredging in the Sulina Branch," have been published in the minutes of the Institution, I need only here describe, as concisely as I can, the nature and result of the works which have been undertaken and completed below Isaktcha since 1856 in the river itself.

At the creation of the Commission, the depth of the navigable channel between Ibraila and the bars of the Kilia and St. George was nowhere less than 17 feet and 15 feet respectively, and as the permanent establishment of 16 feet on the bar of whichever mouth of the Danube might be chosen ultimately for special treatment was all that was then considered necessary for the navigation, no provision was made in my first estimates for the deepening of the river channels between the head of the delta and the Kilia and St. George's mouths. In estimating the cost of improving the Sulina mouth, however, the removal of the numerous shoals in the Sulina branch was, of course taken into account; but before referring further to this subject, I desire to say a few words regarding the removal of an isolated shoal which cropped up unexpectedly several years after the provisional works at the Sulina mouth (which, for economical reasons was selected in 1858 for special treatment) had been successfully completed.

I should premise that in June, 1857, at a period of ordinary summer flood, when the water attains the level of the natural banks of the delta, I found by exact gaugings that the total discharge of the main river in the first reach above Ismail Chatal or Fork, 14 miles below Isaktcha, and 55 miles below Ibraila, was 325,000 cubic feet per second, of which

205,000 escaped by the Kilia branch.* I also ascertained that the minimum depth of the navigable channel in the Toultcha branch close to the Chatal was 19 feet at low water, and 30 feet at ordinary high water, over a width of about 400 feet. The existence of such an excellent waterway at the very threshold of the Toultcha branch was naturally regarded as very satisfactory, its navigable section being much superior to the normal sections lower down stream. In 1869, however, the depth of water at the same spot was found to be less than on a similar shoal which had always existed, and which will be referred to presently, at the entrance to the Sulina branch, 11 miles below Ismail Chatal. The appearance of a new and menacing obstruction at such a critical part of the river, gave rise to great anxiety, and dredging was at once resorted to as a means of giving the speediest relief to the navigation.

In spite of long-continued dredging operations, and of a temporary improvement by natural scour in the winter of 1871–72, the depth of the water at zero or lowest water over the new shoal in June, 1873, was reduced to 9 feet, or 3 feet less than in the worst part, at that time, of the Sulina branch. This serious diminution in depth at a vital point of the river called for immediate action of a drastic kind, and accordingly, before the end of the campaign of 1873, the main portion of the training works I had designed three years before were completed with great rapidity by Mr. Kühl, M. Inst. C. E., the able and energetic resident engineer of the Commission. From that time to the present the channel at Ismail Chatal has gone on steadily improving, and is now in a better condition than it has ever been before in the memory of man. The unique work that effected the cure—for the channel has never given any trouble since—is simply a curved dyke of rough rubble stone, 1,400 feet in length. This longitudinal training wall is connected with *terra firma* at the Chatal by a straight groyne, 600 feet in length, of the same height as the dyke itself.

The Sulina branch discharges 24,000 cubic feet per second at ordinary high water, or $\frac{2}{21}$ of the total volume of the Danube, when the river is 9 feet above the level of the sea at St. George's Chatal. At low water, or 1 foot above the sea at the same spot when the river in its course of 50 miles to the sea has a slope of only $\frac{1}{4}$ of an inch per mile, the discharge is reduced to 5,300 cubic feet per second. At extraordinary high water, when the inclination is 3 inches per mile, and the whole delta is submerged, the volume is increased to 70,600 cubic feet per second.

Although the volume of water discharged by the Sulina arm varies from 1 to 13, and the velocity of the current varies from $\frac{1}{2}$ mile to $4\frac{1}{2}$ miles an hour, the weight of sediment carried in suspension varies from a minimum of 12 grains to a maximum of 840 grains per cubic foot of water, or 1 to 70. The mean annual discharge of sediment by the Sulina is 5,000,000 tons, the proportion in weight to that of water giving an average of about $\frac{1}{3000}$.*

When the improvement of the Sulina branch was first decided upon, its course of 52 miles was impeded by eleven bends, each with a radius of less than 1,000 feet, besides numerous others of greater radius, and its bed was encumbered by ten shifting shoals varying from 8 to 13 feet in depth at low water. The width of the upper part of the branch varied from 500 to 800 feet, and that of the lower half from 600 to 750 feet. In the first case shallows existed wherever the width exceeded 500 feet, and in the second there was no appearance of a shoal where the width was limited to 600 feet. Consequently the first projects which aimed at securing a minimum depth throughout of 15 feet were designed to narrow the river to the width that nature herself seemed to indicate as sufficient to maintain the depth desired. Experience, however, has since shown the necessity of narrowing the channel to 400 feet in the upper section, and to 500 feet lower down, in order to maintain the depth obtained either by dredging or natural scour.

Owing to a want of funds the Commission was only in a position to proceed

* The flow past Isaktcha at extraordinary high floods, when the delta is submerged, is estimated at 1,000,000 cubic feet per second.

* The mean annual discharge of sediment of the whole river before it divides at Ismail Chatal, in the ten years ending 1871, was 67,760,000 tons, the maximum discharge (1871) being 154,000,000 tons, and the minimum (1866) 12,500,000 tons.

slowly with the river works, and many years elapsed before a clear gain of 4 feet in depth could be obtained throughout the branch. During that period of transition it was proved over and over again that dredging, although often resorted to to give temporary relief to the navigation, was altogether inadequate to ensure a permanent improvement, for, owing to the vast amount of detritus carried in suspension, as well as to the sand rolled along the bed of the stream, the shoals, which were still untouched or but partially treated, were invariably in process either of augmenting in volume and height during floods, or of deepening and diminishing in bulk as the water subsided. Occasionally a shoaling of from 2 to 3 feet would take place, when no particular reason for its formation could be assigned, and until the unexpected obstruction was removed by dredging much inconvenience was experienced by the navigation.

Time only allows me to give a very meagre description of the river works which have been constructed to regulate and fix the channel, and two examples must suffice as types of the methods which have been employed, as a rule, to attain the end in view.

The object of the first works was to confine the waters within certain limits where required, so that the floods might operate in deepening the channel sufficiently, but not so violently as to cause excessive scour, an effect which only gives an abnormal deepening, not needed at the expense of the river lower down where the depth is already insufficient for the navigation. As before remarked, this "*juste milieu*" of width was found in practice to be 400 feet in the upper half of the Sulina and 500 feet in the lower half, and these widths have accordingly been adopted. The worst shoals in the Sulina branch, before its correction was taken in hand, were found at St. George's Chatal and at Algany, 3 miles lower down. The latter being then the worse of the two was attacked first, and will be first described.

In its natural state the shoal extended from bank to bank, a width of 700 feet, and the depth over it at low water was only 8 feet. The first works consisted in the construction of several low groynes or spurs from the left or concave bank, and in the closing of a subsidiary stream. These preliminary works produced an appreciable improvement in the first instance, but as two years afterwards the shoal began to deteriorate, it was then decided to confine the river within artificial works 500 feet apart carried up to the full height of the banks. This was accomplished by the construction of a curved longitudinal dyke joined to the left shore by a straight groyne and by the projection of several other groynes and a small longitudinal work from the right bank. The channel was dredged at the same time, as, unlike most of the other shoals, the bottom consisted of hard clay which resisted the erosion of the current. Notwithstanding this treatment, a depth of from 13 to 14 feet could only be maintained by occasional dredging, and it was not until the channel had been narrowed to 400 feet that the existing depth of 15½ feet could be constantly maintained without further artificial aid. The groynes, as at all the other shoals, are composed of fascines of willows or reeds bound together with iron wire on frameworks of timber sunk *in situ* and revetted with stones from the bed of the stream up to the level of high water. The root ends of these spurs speedily become incorporated with the river banks, but their outer ends require careful maintenance to protect them from the attacks of ice in winter when the navigation of the Lower Danube is generally suspended for a period of two or three months.

In my first project for the correction of the Sulina branch, I recommended the opening of a new entrance from the Toultcha branch favorable in its direction for the navigation, and intended to supersede the old entrance at St. George's Chatal, which was difficult both of ingress and egress, owing to its exceedingly tortuous and shallow channel. This scheme lay on the shelf until the improved finances of the Commission enabled it under my advice to undertake the work in 1880, and to complete it in December, 1882. The state of the old Chatal underwent many vicissitudes, until it was finally abandoned. For want of money nothing but dredging could be done in the early years of the Commission to maintain the channel at the depth of 12 feet at zero or lowest water. In 1865, however, this constantly-recurring expense was found to be so unsatisfac-

tory, and the persistent erosion of the Chatal point by strong currents and floating ice became so alarming as to cause me to advise the Commission to lose no time in constructing protective and training works at the Chatal, and to exhaust every legitimate endeavor to improve it before resorting to the plan of cutting an entirely new entrance, which, at such a delicate point, would entail a certain amount of risk, and an outlay which could be better applied for the moment in the construction of still more urgent corrections down stream. My proposition being accepted, the first work was begun in 1865, and consisted of the revetment of the concave bank, and a continuation of the latter on the same curve, 600 feet, by means of what may be called a half-tide spur of rubble stone 350 feet long, terminating in the Toultcha branch at a depth of 16 feet at zero. The spur effectually stopped any further erosion at the Chatal point, but failed to give any additional depth, and it was not until the work was crowned with a palisade of timber brought up to the level of high floods, combined with the projection of a half-tide straight groyne from the opposite bank, thus narrowing the pass to 450 feet, that an appreciable deepening of the channel occurred. This improvement continued until 1870, when the descent of an extraordinary high flood threw down such a mass of deposit at the Chatal that the available depth was at once reduced to 8 feet at zero, thus diminishing the depth of the channel fully 4 feet in less than three weeks' time. This rapid shallowing, following a gradual improvement of five years' duration, seemed to prove that the width between the curved spur and the opposite bank was still too great at times of high flood to prevent injurious deposit at the Chatal channel, and therefore the straight groyne was at once raised to the level of the river bank. This additional work, together with dredging, soon restored the channel to its former condition, and the improvement continued until April, 1875, when the survey showed a fairly good channel of 15 feet at zero.

Shortly after that time, however, the depth again began to fluctuate between 11 and 14 feet, and these constant changes in the bed of the stream, added to the inherently vicious direction of the entrance itself, became at length so intolerable to the long steamers which now trade to the Black Sea ports, that urgent demands were made for the cutting of an entirely new entrance. This request, as we have seen, was complied with.

The new cut, $\frac{1}{2}$ mile above the old Chatal, has a length of 3,300 feet, an average depth of 24 feet, and a bottom width of 300 feet, with slopes of $1\frac{1}{2}$ to 1 and 1 to 1. It was begun in June, 1880, and its contents of 1,057,000 cubic yards of clay and sand were removed by the aid of dredgers, floating tubes, and hopper barges by December, 1882, when the new channel was opened to the navigation. In the four following months there was a silting up of 3 feet in the new channel, and of 4 feet in the old one, owing to the velocity of the current in both channels being considerably less than in the reach immediately below them, and it was not until the old branch was entirely closed by a solid dam that the *regime* of the lower part of the Sulina branch was restored. An accelerated current swept away the recent deposits in the new cutting in proportion as the dam in the old branch was raised to the water-level, and within two months of its completion the whole mass of sediment, 187,000 cubic yards, an accumulation of less than six months' duration, was swept away by natural scour. The new channel then assumed the normal area of the improved sections of the river, and, with but few modifications, has retained it to the present time.

The programme of the Commission for improving the navigation of the Lower Danube is on the eve of completion. Between the ports of Ibraila and Sulina there is now everywhere a navigable depth of from 17 to 20 feet at the season of high water, and a minimum depth of 14 feet at low water. In the Sulina branch nine of its worst shoals have been successfully dealt with, three cut-offs have been made, by which the river has been shortened 2 miles, eight of its worst bends have been entirely suppressed, and a length of 10 miles of stone revetment to protect the banks has been constructed. The total cost of those river works, including maintenance and dredging, has not exceeded £300,000.

At the Sulina mouth, where there was only a depth of from 8 to 10 feet before

the construction of the piers, the depth for many years past, unaided by dredging, has not been less that 20½ feet. The cost of the piers, including their maintenance to the present time, has been about £220,000.

The effect of these improvements has been to increase the trade from 680,000 gross tons in 1859 to 1,530,000 gross tons of 2,240 lbs. in 1883, and to lower the charges on shipping from an average of 20s. per ton for lighterage before the deepening of the Sulina mouth and the improvement of its branch to less than 2s. per register ton at the present time for commission dues.

Two-thirds of the trade are now carried by English steamers, which usually ascend to Galatz and Ibraila at ordinary high water to discharge merchandise or coals, and to load with grain. At seasons of low water they prefer, as a rule, taking in their cargoes at Sulina from iron lighters drawing from 8 to 12 feet, and carrying cargoes of from 300 to 1,000 tons. The average charge for conveying grain down stream by these lighters, which are towed by steam tugs from Ibraila to Sulina, exclusive of loading and discharging, is 0.20 of a penny per ton per mile, and 0.33 of a penny per ton per mile for the transport of coals from Sulina to ports up stream.

It may be encouraging to young engineers who have difficult river and sea undertakings on hand—in the ultimate success of which they themselves have implicit faith—to learn that the works I have just described are almost identical with my first projects in 1857, which were emphatically condemned in 1858 by an international commission of distinguished engineers—who had never visited the grounds, in the following terms: "The Commission cannot recommend the application of the proposed system of improvement, which offers no guarantee of success. As for the projects for the Sulina mouth and branch, they ought not to be carried out; their success is very uncertain, they will be of no real use; they will cause the total loss of very large sums of money, and will even throw obstacles in the way of existing navigation." And even in stronger terms than these they condemned my plan of provisional piers at Sulina, which in three years' time (1858–1861) increased the depth on the bar from 8½ feet to 17 feet, at an expense of only £86,000. These provisional works they reported in 1858, to their Governments, "should be immediately abandoned, if already commenced, for not only would they be useless for the purpose intended, but the guiding piers themselves would speedily be destroyed by the force of the waves, owing to their feeble section."*

As a commentary on the above, I need only draw attention to two facts—namely that the execution of the works so unsparingly criticised in 1857, has already effected a saving of upwards of £20,000,000 sterling, and that experience has abundantly proved that the predictions of a rapid silting up to seaward of the Sulina piers, which were so prevalent at one time, were happily unfounded; for, on the contrary, the entrance was never so free from sand banks as at this moment, as will be seen at a glance on referring to the last survey of the Sulina mouth in November, 1884.

I cannot quit this subject without calling to mind the eminent services of my steadfast old friend, Col. Sir John Stokes, K. C. B., R. E. (whom I am happy to see in front of me to-night), whose prompt and energetic action at moments of financial and other difficulties, which beset the European Commission of the Danube during the fifteen years from 1856 to 1871 that he acted as H. M.'s Commissioner, has contributed more than anything else to the complete success of the governing body, which for the last twenty-nine years has exercised almost sovereign power on the lower part of the river.

And now, I am happy to say, our bad quarter of an hour is at an end, and that it only remains for me to conclude my lecture by a few practical observations, which have suggested themselves to my mind, on reviewing the facts which I have ventured to bring under your notice this evening.

* As a substitute for the parallel pier system at the mouth itself, the Technical International Commission recommended the construction of a lateral canal 16 feet deep to the St. George's branch of the Danube from a point on the sea-board about ¼ mile to the north of St. George's mouth, at an estimated cost of £360,000. If this plan had been executed, the cost of the canal up to this time, including maintenance, would have amounted to at least £600,000, and the navigation, instead of enjoying, as at present, a depth of 20½ feet at a wide, open mouth, would have been compelled to enter and leave the Danube through a narrow locked entrance of solid masonry, with only 16 feet of water over its sill.

It may have been remarked that I have taken some pains to ascertain the actual available depths for navigation in the principal inland waterways of Europe. This procedure has involved a considerable amount of correspondence with some of my colleagues at home and abroad, to whom I take this opportunity of tendering my grateful acknowledgments for the kind manner in which they have responded to my solicitations, for certain precise information, within their personal cognizance. The question of improved inland waterways is one that eminently deserves the attention of English engineers; but, unfortunately, since the establishment of the railway system in this country, the construction of canals and the improvement and canalization of rivers has ceased to be appreciable. Such, however, is not the case abroad. On the great inland navigations on the Continent the permanent acquisition of even a single foot of additional depth between great trading ports in the same or in an adjacent river basin, is considered of immense importance, and worthy of being attained at a great cost; and striking examples of this assertion, in France and in Germany, I have endeavored to lay before you. In no other way than by deepening existing channels and by acquiring new ones of comparatively great depth, can a wholesale and wholesome competition with railways for the transport of heavy goods be brought about. With regard to the permanent deepening of large rivers without the aid of locks, the question is a very difficult one, and, unfortunately for civil engineers, there is no golden rule to affect this grand desideratum; for every river must be studied *per se*, as it by no means follows that a system of improvement that has answered well at one spot will be equally successful at another. Where a large river has many shifting shoals throughout its course, it is comparatively an easy matter to get permanently rid of one, two, three, or even more of them; but the crucial difficulty, especially in rivers heavily charged with detritus, is to get rid of every one of the shallows down to a depth where water transport can successfully compete with railways.

If, for instance, only a single shoal remains, which demands transhipment at certain seasons of the year between two important seats of trade on the same river, that shoal, like the weakest link in a chain, which is the measure of its strength, will be the real standard of the value of the river as a navigable highway. Again, until rivers in different basins are radically dealt with so as to insure a sufficient navigable depth at all seasons, it is almost useless to join them by constructing canals deeper than the river channels they connect. Thus, for example, the Ludwig Canal joining the Danube and the Main can never be profitably worked until the navigable channel of those rivers has been very materially improved and the same remark applies to the proposed canal between Vienna and Oderburg, at the ends of which the Danube and Oder have but comparatively narrow navigable channels. It goes without saying, that intractable rivers can only be profitably dealt with by using them as feeders for lateral canals furnished with locks, or by canalizing the rivers themselves, with ample provision by means of movable dams or otherwise to enable the floods to pass freely without detriment to the navigation. In either case, apart from the question of depth, the locks should, wherever practicable, have dimensions approaching those now being constructed on the Lower Seine. It need not be added that another element required to enable a canal to prosper as a great carrying highway is a great increase in speed, an improvement which can only be accomplished by enlarging the sectional area of the canal, by the best known mode of traction, and by protecting the banks against pernicious erosion.

As I remarked at the beginning of my lecture, it has not been my intention to discuss the relative cost of rail and water conveyance. Railways will prosper where water communications languish, when the latter labor under great physical difficulties, as on the Rhone and the Ruhr, and where, as in the United Kingdom, canals are handicapped by frequent lockages and insufficient sectional area.

On the other hand, waterways will flourish, as on the Seine, in Belgium, and in Southern Germany, where the winters are comparatively short, where tolls are merely nominal, where locks are large and infrequent, and where a good navigable depth is constantly maintained, so

that vessels of large tonnage—*the great desideratum* in economical water transport—can nearly always be profitably employed.

I have abstained advisedly from alluding in this discourse to the Corinth Canal, now in progress, or to certain well-known projects for overcoming isthmian difficulties of a like nature elsewhere, either by means of artificial water channels or by ship railways. It is one of the traditions, I believe, of this Institution, to discourage anything like a serious discussion, within these walls, of public works that are still in embryo, or under construction, and of course I shall not attempt to infringe this salutary unwritten law. I may remark, however, with regard to such great enterprises, that whatever may be their ultimate fate, the number of great isthmian schemes must necessarily be very limited, and that in this respect they differ materially from ship canals of an inland, and therefore of a less ambitious character. Whatever, for instance, may be the result of the Liverpool and Manchester scheme, now before Parliament, it is evident, I think, that a grand future is open to works of that class; and I venture to predict that the improvement of water communications between the sea and inland towns of importance, by means of canals or of deep, open channels planned so as to *aid nature* in maintaining permanently their increased depth, will continue to go on briskly after the last ghost of a practicable inter-oceanic waterway has been finally laid.

## SOME THOUGHTS ON ARCHITECTURAL TRAINING.

A Paper read before the Architectural Association by W. J. N. MILLARD.

From "The Building News."

In offering you a few stray thoughts on architectural training, a question which has for a long while interested me, I certainly cannot claim originality as to the subject chosen, nor perhaps for many of the ideas I have attempted to string together; but I trust you will allow the apparent staleness of my subject to be outweighed by its importance to us and its peculiar fitness for discussion by such a body as our Association. Since, moreover, it seems to be a question on which the last word has not yet been spoken, by any means, we may possibly still find one or two points worth considering, or even reconsidering, in spite of everything that has been said and written concerning it. In fact, regarding some points, one is half tempted to ask, "What has all the attention given to the matter of late years really amounted to, so far?" To say nothing of the destined victims themselves—the pupils-to-be—standing, so to speak, on the brink of the profession, about to take their great "leap in the dark,"—are the parents and guardians, up to the present time, any better informed, or enabled to inform themselves much more clearly than hitherto, about what is involved in an architect's training and subsequent career? What are the main requirements and the chief conditions essential to success, or, at least, to avoidance of failure, in such an undertaking? Here, to begin with, lies the possible source of much mischief which might be rendered more preventible than it is by us architects. The immense importance of any reliable information that can be obtained with regard to an architectural career, before committing a youth to it for life, must be obvious; and surely it rests with us, and us alone, to enlighten the outside public in this respect. As yet, however, I fail to see where the parent is to turn with certainty of obtaining anything more than the most meagre hints to help him to a decision in such a case; and still, it seems to me, it ought to be quite possible to afford him ample means of fully weighing a step so grave in its consequences for his *protege* before letting him take it. For instance, a students' manual or text-book might be drawn up, one would think, and issued under the joint sanction

of the Institute and the Association; embracing the entire training of an architect, and setting forth in detail all the various branches of study, with the order in which they could be best taken up according to circumstances, as well as other items of information bearing on the subject. To accomplish this much effectually, would perhaps call for a little more unanimity than seems to have prevailed until now, as to the main lines to be laid down for an architect's training; but I hope we may really take it that all the interest recently exhibited about the whole question is evidence, at least, of a genuine desire for some more general agreement. The project of a student's textbook to be published by the Institute, was put forward in a paper by Mr. Phené Spiers, as long ago as the general conference of 1871; but, for some reason or other, it seems to have fallen flat. May-be vested interests in the pupil-farming system were too powerful in those early days for any so radical an attempt at reform. It is true, the A. A. "Brown Book," and the lately-issued "Kalendar" do give particulars of many things a student may want to know, such as our classes and the examination, thus fulfilling their purpose well enough, each in its way. The "Kalendar" is now to include the questions set at the previous examination; but we seem to be in need of something far more comprehensive in its aims—a production that should if possible be the outcome of the united counsels of all those best qualified to advise, and so be rendered valuable as a guide to parent, principal, and pupil alike. Since the feelings and opinions current amongst juniors of the profession would have to be taken particularly into account in preparing any such work, we could not be doing amiss this evening to quietly discuss a few matters of which it might treat. With this object I proceed to throw out a suggestion or two for your consideration. To begin with, then, it would not be inappropriate, by way of an introduction, to call to mind what is usually comprised in an architect's practice—to which his training is professedly a preparation, and to afford some conception of the wide range of subjects he is expected to deal with. How, for instance, he is of course supposed capable of designing almost anything, from a Christmas card to a cathedral; and is liable at any moment to be appealed to as an authority on nearly all conceivable matters, from a leaking gaspipe to a question of church ritual arrangement; or, again, to be called away from playing the part of a building detective to decide upon a doubtful point of archæology, not to mention other things innumerable, showing clearly that, although architecture is the work of architects, the converse will scarcely hold good invariably. It might be interesting and instructive, in the next place, to follow this up with the means commonly taken to equip the aspiring youth for an enterprise of such magnitude, giving a brief unvarnished recital of the time-honored course of procedure so familiar, I will not say endeared, to most of us; recounting how the raw pupil gets pitch-forked, all unprepared as he is, into an office, the busier the better; and, how, only too frequently, his wasted years of innocence are terminated by rude awakening to what he ought to have been learning all the time on finding himself, at the expiration of his articles, helpless. This to anybody of an inquiring turn of mind, must bring home the question, supposing it has never occurred to him before, whether no improvement is possible, whether no saving of valuable time can be effected in a pupil's usual course of training; and, if it can, how? Even so much as to put him into the way of teaching himself, to show him how to use his eyes and pick up what he can on his own account, is not unfrequently to do him quite a good turn, as elementary instruction for architects goes nowadays. Hitherto, a lurking sort of idea seems to have possessed parents, architects and pupils alike, that for about the first year, at any rate, it cannot really matter so very much how a pupil is employed, and, as I have known it to be said by an architect, too, that "a year or so of office drudgery will do him good!" Will it? May we feel quite certain it will do no harm? Why, herein, possibly, lies a clue to the mystery of that spectral apparition we so often see, calculated to touch the conscience of architects (if anything will)—I mean the time-expired pupil, wandering round disconsolate in search of his first berth as an assistant; whilst his good friends and relations are grow-

ing every day more and more concerned about him, marveling how it is he does not manage to "do something." Poor fellow! Alas, generally speaking, it is so precious little he can do. He tells you naïvely how he would so like to get with some "good man," where he would "learn something." That alone speaks volumes. He finds, in fact, he has just come to a most critical turn in his course. For a last resource, perhaps he goes, out of sheer desperation, as an "improver," in hopes of learning something. Save in certain exceptional cases, I can seldom hear of an instance of that nondescript, the "improver," without suspecting there must be something wrong somewhere, and, not improbably, as much of misfortune as fault on his side. Altogether, is it not enough to suggest a doubt, whether the ordinary architect's office is invariably the best possible place for a boy fresh from school; and whether the practising architect, be he prosperous or struggling, is precisely the man to undertake the responsibility of such a charge? Almost any head draughtsman can tell you how young pupils are usually regarded as a nuisance in an office, secretly or openly, until they have proved themselves to the contrary; but how they must, of course, be tolerated for the sake of their premiums and the dim hope of their making themselves useful some day before the term of articles is "up;" and how it is time enough to trouble much about them when (if ever before then) they become, somehow or other, sufficiently advanced to be trusted with office work of any consequence. To slightly vary the well-worn metaphor—"as the boy is to the man, so is the pupil to the architect." We do not find the question of "bringing-up" lightly regarded by the majority of thoughtful parents in respect of their children, not, at least, so long as they are still too young to take to architecture as a profession. And seeing that, in other branches of education, the art of teaching is generally held to require some sort of special training, and even special gifts, for it to be followed with success, the wonder is how intelligent men of the world, who have to decide on a career for their sons, can go on supposing that corresponding conditions may be dispensed with in an architectural education. But, as yet, how are they to be aware whether or not they ever incur any risk at all of such conditions being unfulfilled, unless, indeed, the architects they treat with should themselves say as much, a course of procedure only conceivable on the assumption, in the first place, that even they are firmly persuaded to that effect. Happily, at last there does appear a tendency, actually amongst architects, towards agreement to this much, at any rate, viz., that a regular course of distinctly preparatory training is almost essential for a pupil before being launched straight into an office if he is to derive full benefit from what he sees going on there. This point, finally accepted, would involve the further one, as to what should be the nature of such preparatory work; in short, how best to begin an architect's training. Or is this ever to remain a case for "toss up?" By no means the least part of the difficulty in deciding on any course arises from the very variety of studies the pupil might begin with, coming under the four main heads of Art, Science, Literature, and Practice. One thing, at any rate, is pretty certain—he cannot plunge indiscriminately into them all just at first. No sensible man, with a dozen important affairs to attend to, will attempt to take them together in a lump, but will at once set about arranging them in some suitable order. No beginner at architecture can be reasonably expected to acquire a dozen branches of professional knowledge all at the same time; he needs careful guidance—nowadays more than ever—as to the best order in which to proceed; even supposing the economizing of time be his sole object. Then another difficulty meets us in the fact that the same course may not be equally well suited to varying capabilities. Yet, surely, it ought to be possible to indicate a path which no one could be any the worse for pursuing, a certain distance at least, to begin with—that is, if he is ever to be an architect at all. Doubtless, we shall hear plenty of excellent and powerful arguments in favor of a preliminary course of technical education or applied science rather than purely artistic training. I venture, with all respect, to put in a plea for the latter being made much more than it is, the basis and backbone, as it were, of an architect's education and whole career, the very foundation to build up

from. I should like to see an architect commence oftener with a sound artistic training, including geometry and perspective, side by side in a school or studio with other art students. It is rank heresy, of course, to breathe the shadow of a doubt as to the immense advantages of a so-called practical training; but it may be at least permissible to discuss whether this is always the best way of beginning, and whether a thorough knowledge of what comes under the head of practical work might not be acquired by a student just as well, or even better, than in shorter time after he had advanced somewhat and there was a likelihood of his receiving the bearing of such studies and of then realizing the unquestionable necessity for his mastering them as one main condition of ever being able to practice his profession. No more potent influence was ever invoked in aid of successful teaching of any sort than the infection of the pupil himself with a desire to learn. This, if possible at all, is most likely to be brought about with work he most cares for at the time. If, therefore, an architectural beginner's own inclinations lean, ever so slightly, towards art rather than science, would it not be a trifle unwise to disregard them and to court failure, by putting him through the "mill" of a scientific or practical training from the first—beginning, as it might prove at the wrong end? The consideration of what he himself may want to be taught will be hardly worth neglecting entirely for the sake of compliance with some supposed infallible programme of cut-and-dried correctness. Rather let the loose rein, given in the first place to his natural tendencies, be used as a means to lead him little by little. All in good time, no doubt, he will want to know about practical matters, and will be far more disposed to devote himself to the intelligent pursuits of them—in view of their absolute indispensability to him as a practising architect—when he is old enough to feel clearly convinced of this fact. And it is a fact, the full importance of which he will never be made to feel by mere reiteration. Again, even in the case of those who may not, so far, have given unmistakable indications of genius, or whose natural bent still rests undefined; just average young beginners, say, with all their inherent imperfections, carelessness, ignorance, laziness, or stupidity; a preliminary trial of artistic instruction is still as likely as anything else to enlist their better qualities, and has at least the recommendation of leaving no unpleasant distaste or harmful results—supposing it should, after all, fail to disclose latent talent. Nor need it be lost time, since every architect, to be worthy of the name, must at some period or other attain to a certain amount of proficiency in freehand drawing—as distinguished from mechanical—and the earlier he does this of so much the more service will it be to him. It is something he can apply in his everyday work, and thus, at the same time, ensure from becoming rusty and useless, as may easily happen with some kinds of knowledge if acquired sooner than need be. How an architect can gain command of his pencil too soon is difficult to make out. But beyond all this, is it not also worth our while to consider, for a moment, the positive harm that may be done to any youth blessed with so much as a single spark of artistic fire, by deferring the careful and systematic development of such a gift until after he has been wearied and nauseated with what may well appear to him at first as the less attractive and less stimulating side of his profession? If there be one thing more than another that needs, and at the same time repays, skilful tending, from boyhood upwards, it is surely this lamp of art; whereas, on the other hand, its flame is by no means to be kindled at will, just any moment a man may decide to "go in for the artistic." The comparative rarity of a wild plant may sometimes be apparent only, rather than real, owing to its general unobtrusiveness: but granted, that, in this case, the shoot might be but a feeble one—the smaller the growth, the greater the need, perhaps, to prevent its being blighted and hidden for ever; and the season for bringing it forward to good purpose, once let pass, may never recur. In such an instance, it would seem, anyhow, to be running a smaller risk to postpone awhile the taking-up of some other branches of study. Every now and then, in looking at executed designs, one cannot help feeling that the authors might easily have been made so very much more of as artists, by other training; to judge from the evidences of considerable artis-

tic power—somehow strangely undeveloped—marking their work, which differs, at the same time, distinctl from that of the simply feeble designer, destitute of any ideas of his own, and only just sufficiently clever to ape the art of better men. Ask many a worthy practitioner whether, in his heart of hearts, he does not deplore his lack of early artistic encouragement and guidance, and feel that this might have made all the difference. To save even a single student from the fate of turning out, in an artistic sense, a dwarf or a cripple for life—if it can be prevented—appears well worth the attempt. To catch hold of him and turn his brighter side to the light; to draw out his finer feelings whilst yet unblunted; to arouse in him a healthy enthusiasm through the sympathy of his fellow-workers in a congenial pursuit, just at an age when he is most impressionable, may be doing a truer kindness than to ply him with all the most admirable instruction in the world, before he can half appreciate the good of it. As I believe in a good art school for the beginning, so I know of nothing equal to a good office for the finishing of an architect's training—outdoor study and travel coming in very largely between whiles. I will just allude to a proposal I made here, on a former occasion, for obtaining the privilege of a seat in a good office, by way of a "finishing," for such as should distinguish themselves in preliminary study. Might not the Architectural Association set an example of founding scholarships entitling the holders to serve for a period a sort of advanced pupilage in one or another of the leading offices, where they would have the advantage of doing good work along with other picked men? Any number of poor students would regard such a prize as indeed something to aim at; and further, we should be thus helping, in a way, to bring on a more accomplished race of architects. For whatever is gained from any course of instruction depends not only on whom it is the pupil works under, but quite as much on those he has to work with: figuratively speaking, they constitute the very atmosphere he breathes. Indeed, oftentimes in after-life, on looking back to such days, a man may be able to trace some decided change of direction in his career to the fact of his having then chanced to come in contact with certain other minds of different calibre from his own. A paper on "Architectural Training," however limited in scope, would be incomplete without some reference also to the examination. Now, the architect's calling may be said to combine the pursuit of an art with the practice of a profession. No man may lawfully set up as an attorney, a doctor, or even a druggist without first satisfying an examination test. Anybody may dub himself "architect" who chooses to, but so can anybody proclaim himself a painter, a sculptor, or a musician, without, however, any other folks taking it very seriously to heart. In these cases an abuse of title corrects itself in the long run. May not a like result be looked for in architecture, if only the standard in it of artistic attainment be more and more raised? But yet, on the other hand, how is it that people do not, as a rule seem to put such implicit faith in their architect as they will, for example, in their legal or medical adviser? Is it not mainly because these latter can invariably offer a sound guarantee to begin with of proficiency in their work up to a certain point? If, then, this be the true reason, it must manifestly tell to the architect's advantage also, as well as to his client's satisfaction, to have a similar assurance to give, as far as any examination test can be fairly applied and without prejudice to his position as an artist, still leaving that point to be determined in the same way as in the sister arts. I make no apology for assuming all along the possession of artistic ability to constitute one of the truest claims to the title of "architect." To some, of course, it may seem but a small matter for regret if by clumsy nursing we do manage to "choke off" or maim so many "budding artists" a year, leaving only the hardier survivors to flourish in spite of it; but do not let us forget that in the training of our pupils lies the key to the future of British architecture; and even for the present one does not hear many serious complaints of our poor profession being actually glutted with artists, whatever other forms of depression it may be laboring under. It is to be hoped there may ever continue to be pupils who, by force of talent, with or without good training, will in due time win credit to themselves and their profession; but we are dealing

with a matter affecting not a small minority only of exceptionally clever men, but that vast majority of average mortals like ourselves, who, whether or no, are some day to adorn or disfigure with their works our streets and suburbs and fair country-sides. Much might be said about a student's more advanced work and his preparation for practice. Important and interesting as these questions would be found, they must sink into insignificance beside the great initial one of how the training of an architect should be *commenced;* since in this, as in many another undertaking, it is the first move—the easiest one to make—which may influence so incalculably all that follows. And together with this point goes the one—at the root of the whole matter—whether some means or other cannot be devised for putting things a little more clearly and fairly before parents and guardians. In pursuance of my endeavor throughout to regard this subject in as broad a light as possible, rather than in detail, I will conclude with a proposition that may now appear to many self-evident, but, nevertheless, one, if true, whose more universal and loyal acceptance by architects in days past might perhaps, among other results, have rendered needless, not only this evening's discussion, but the very existence of the Architectural Association itself—viz., that our whole profession, as a body, is responsible for the training of its pupils.

## STEEL SHIPS.

From "The Engineer."

It is now just ten years since the steel manufacturers of this country succeeded in producing a material suitable for the purposes of the shipbuilder and marine engineer. Previous to that time many attempts had been made, both in Royal and private shipyards, to employ steel in the construction of ships; but the results were not so generally satisfactory as to encourage further developments in that direction. The steel then being made was variable in its qualities, so much so that angle bars, which were very ductile at one extremity would sometimes be exceedingly brittle at the other. The behavior of the material was, indeed, very erratic and unsatisfactory. Some plates and bars would show the best qualities of tenacity and ductility, while others from the same batch would evince the possession of the several characteristics of hard tool steel. After much labor had been expended upon a steel plate, and when it was riveted in place, it would suddenly become fractured without any warning, and from no assignable cause, except, perhaps, change of temperature. The Admiralty were the principal users of steel in shipbuilding at that time; but the employment was limited to deck flats, stringers, and longitudinals, with the view chiefly to effecting economy of weights. Under no circumstances was it considered safe to use steel for the outside plating of her Majesty's ships. The French Government were more enterprising in this particular, and in 1874 it was found that, notwithstanding the treachery and imperfections of the steel supplied to their dockyards, they were able, by carefully observing certain precautions, to work that material into their ships upon a larger scale than our own naval constructors felt justified in attempting. The keystone of the difficulty was to be found in this very question of care in manipulation. It was not doubted that the behavior of the steel was governed by certain laws, and that a careful observance of those laws would be followed by success, so far as the manipulation of the material was concerned. But then, dockyard workmen are not skilled metallurgists, and to build ships with a material that required such careful handling was not only commercially impossible, but also impracticable, even at a Royal dockyard. Moreover, there was always the risk that by improper treatment the steel might be put into such a condition of initial strain by reason of changes in its molecular arrangement, as to cause a disaster to occur at sea to a vessel by a

rupture occurring at a place where undue internal strain would be wholly unsuspected. For these reasons, then, our shipbuilders had no confidence in steel, although they had every desire to employ a more tenacious and ductile material than wrought iron if it could be produced at a moderate cost.

It was in 1875 that Sir N. Barnaby, then Director of Naval Construction at the Admiralty, uttered his famous challenge to the steel makers of Great Britain in the the hall of the Society of Arts —at the annual session of the institution of Naval Architects. That challenge was taken up at once, and in the following year Mr. James Riley, the manager of the Landore-Siemens Steel Works, appeared before the members of the same institution with a statement showing what had been done by the company he represented towards meeting the requirements indicated by Sir N. Barnaby. The Director of Naval Construction had said in the previous year—"The uncertainties and treacheries of Bessemer steel, in the form of ship and boiler plates, are such that it requires all the care which it has had bestowed upon it at L'Orient to avoid failure;" and had further declared that we wanted "a perfectly coherent and definitely carburized bloom, or ingot, of which the rolls have only to alter the form in order to make plates with qualities as regular and precise as those of copper and gun-metal, and we look to the manufacturers for it." Said he. "I am ready, for my part, to go further than the French architects have gone, and build the entire vessel, bottom plates and all, of steel; but I know that at present the undertaking will involve an immense amount of anxiety and care." By the spring of 1876 the Landore-Siemens Company had satisfied Mr. Barnaby and the Admiralty so far that they were then fulfilling a contract for the manufacture of steel for the entire hulls of the two armed despatch vessels Iris and Mercury, which were ordered to be built at Pembroke Dockyard. Lloyd's Register at once gave attention to the matter, caused a vast number of experimental tests to be made upon the new steel, and so satisfied were the committee with its behavior that they proceeded without any delay to formulate rules for the construction of steel ships to be classed in their Register. The quality of steel described by Mr. Riley in 1876 is now being produced all over the country, and is known under the designation of "mild steel." Not only the Siemens-Martin, but also the Bessemer process is employed in its production, and attempts have been made to produce equally trustworthy steel by the comparatively new basic process, which, although not quite successful hitherto, will doubtless attain satisfactory results ere long. During ten years the cost of manufacture has been so reduced that the best shipbuilding steel can now be purchased at a lower price than was then paid for ordinary wrought iron. The employment of steel has correspondingly increased with the reduction in its cost, so that at present no less than forty per cent. of the tonnage building in this country is constructed of a material which ten years ago had no commercial existence, and was, indeed, scarcely discovered.

The present seems, therefore, a fitting time to review the developments which have been made in steel shipbuilding, and to consider the experience which has been obtained with the use of steel in the shipyard, and with the behavior of steel under the many tests to which they have been subjected. Hence it was not surprising to find three papers read upon the subject on the first day's meeting of the recent session of the Institution of Naval Architects, and a brief reference to these papers has already been made in the columns of this journal. It is to be regretted that so much of the subject matter of two of the communications referred to related to a personal question with which the Institution had nothing to do. Some of the points brought under the attention of the members by Mr. Martell and Mr. Ward are, however, of the deepest importance to shipowners, shipbuilders and underwriters. These relate to the old question alluded to by Sir N. Barnaby more than ten years ago, when he made his appeal to the steel manufacturers for a trustworthy material. Mr. Martell considers that it is still necessary to impose certain restrictions and regulations upon the use of steel such as he does not deem necessary in regard to wrought iron, and he produces excellent reasons for his opinions. Mr. Ward, on the contrary, has

reached such familiarity in the use of steel that he has become contemptuous with regard to its alleged infirmities and peculiarities. He would, therefore, treat steel in the same way as iron, neither better nor worse—that is to say, he would permit the workmen to heat, hammer and roll it to any extent they may please in fashioning it into shape, setting aside as bad only such pieces as fail under treatment. This is the invariable practice in shaping iron plates and bars, it being assumed that what is not cracked or broken is therefore sound, and fit to go into a ship.

Now, this is admittedly a safe practice in dealing with iron, but it is not everybody who considers it prudent to handle steel in such a way. The instance cited by Mr. Martell of the fracture at sea of a ship's plates which had previously been exposed to undue heat through a fire near the loading berth of the vessel, shows that in one case, at least, mild steel did not behave as ordinary wrought iron would under similar circumstances. On the other hand, as is well known to all familiar with the usual processes of a shipbuilding yard, it is a notorious fact that portions of a plate or bar are frequently heated and hammered without any injurious results following from that treatment. Indeed, if this could not be done, it would be unsafe to build steel ships without at least three times the amount of supervision which is now given to them by surveyors and inspectors. It is, in fact, doubtful whether any supervision at all would be effectual in preventing undue internal stresses from being set up in the molecular structure of the material of which a ship is built, if it cannot be safely handled by ordinary shipyard workmen. The importance of annealing thick butt straps in which the rivet holes are closely spaced, and of riming the punched rivet holes in thick plates of the bottom, may be admitted, without, at the same time, accepting such limitations as would practically exclude steel from mercantile shipbuilding altogether. Generally speaking, whatever wrought iron is capable of withstanding, can be much better withstood by mild steel, and this fact is made apparent by a comparison between the tests to which the two materials are subjected in order to determine their fitness for shipbuilding. The experience of ten years has shown that mild steel will usually endure very bad treatment without being seriously injured in regard to its ductility and tenacity. Instances are very rare in which the bottom plates of a steel ship have been penetrated by taking the ground, and it is not at all unusual for the bent plates to be taken off, rolled fair, and re-riveted in place. Whether such treatment is judicious is quite another matter, and it is very doubtful whether a vessel repaired in such a way is in so good a condition as she was before she sustained the damage in question. From the point of view of a shipowner whose ship is insured, the mode of repairing her to which allusion has been made seems very objectionable; and, indeed, under any circumstances there cannot be that close agreement between the rivet-holes of adjacent plates which is essential to sound work when a stretched plate is rolled fair and replaced in that way. Consequently, while we may admit the possibility of replacing bent plates after being faired by rolling, the advisability of so doing will not be so readily conceded. It is, of course, very satisfactory to find that steel is capable of resisting blows which would penetrate iron, and that in itself should be a sufficient return for the slightly greater cost of the former material, without our wishing to use stretched and over-strained plates simply because they appear to be sound.

Something can therefore be said from both the points of view of the cautious user of steel and from that of the man who would treat steel and iron in the same way. The former must remember that it is the excellence of steel which has made it so popular and inspired shipbuilders with such confidence in its qualities that it is now commonly employed for the most considerably bent, twisted, and furnaced plates in an iron ship's bottom. The latter should bear in mind that the very excellence of the material may often cause defects in its structure to be hidden, which would be revealed by an inferior article; for it by no means follows because a steel plate or bar shows no signs of cracking that it is not overstrained, and therefore impaired in strength. Damage to iron is at once revealed by fracture, but damage

to steel is often known only by a consideration of the treatment to which it has been subjected. While, therefore, steel is, in one sense, far superior to iron as a material for ships, it must yet be treated with more discrimination than iron, simply because it does not so readily disclose impaired conditions of ductility and tenacity. Nine hundred and ninety-nine out of a thousand of the operations in a shipyard are not calculated to do any violence to the structure of steel, if that of punching be omitted, but the thousandth establishes the necessity for taking care. The loss of strength resulting from punching is regularly restored by annealing or riming, and for the rest care must still be taken.

The corrosion difficulty has been overcome by carefully removing the mill scale previous to painting. As soon as this scale is got rid of, the risk of pitting and throwing off paint is at an end. Steel ships, which a few years ago were a source of much concern to their owners in consequences of rapid corrosion, are now no longer worse in that respect than their iron neighbors. Most shipowners take measures to free steel ships of the black oxide scale before they are launched, this being easily accomplished by the occasional application of diluted sal ammoniac or hydro-chloric acid.

The idea that steel ships will prove expensive to underwriters seems to be most fallacious. It is quite true that such vessels permanently alter their form when under stresses which would break an iron ship asunder. Several such cases have already occurred, and the impossibility of restoring those vessels to the same condition as they were in before being damaged has made them constructive total losses. But then the underwriter has held the damaged ship as a set-off to this claim of the shipowner for a new one, and although it has been impossible to make her perfectly fair and symmetrical, she has yet been repairable and made fit for service at a comparatively small cost. Both for the security of life and property, a steel ship is to be preferred to an iron one, and for that reason the rapid increase in the proportion of steel ships built every year is to be welcomed. But to maintain the superiority of steel ships, it is essential that every care should still be taken in the manufacture and testing of steel, and that familiarity with the use of the material should not result in the neglect of those precautions which experience shows to be still necessary in its manipulation, and which are not necessary when we are dealing with iron.

## EARTH CONDUCTION.

By A. J. S. ADAMS.

From "The Electrician."

The future prospects of telephony and practical telegraphy would seem to be somewhat in the dark; but it is nevertheless unwise to discount the possibilities of such systems until we are possessed of a more exhaustive knowledge of the physical forces that are brought into play. Each successive step in elimination and elucidation is found to advance the general subject; and remembering how little is really known regarding some phenomena connected with electricity and magnetism, the surprise is that so much has been accomplished, and that there exists to-day such solid ground for congratulation and encouragement.

Our want of knowledge in respect to the telephone may be instanced by the several theories that have been advanced to explain the precise action of the telephone, and the remaining fact that no theory has yet proved to be incontrovertible, or to greatly modify our earlier conceptions. In respect to line conduction, our imperfect knowledge has been rendered conspicuous by the recent labors of Prof. Hughes, and by the experiments of Mr. W. H. Preece, and there is in connection with this point much yet to be learned. It is possible, however, to go farther, and show that our need of information obtains not only in respect to the

apparatus and to the line, but also in relation to the earth—where the earth's crust forms part of the circuit—and that the earth then exerts no inconsiderable effect upon the general result. In connection with this point it will be admitted that a telephone circuit, of which the earth forms a part, is never so satisfactory as it is where the circuit is wholly metallic, a feature clearly indicated in the interesting paper lately contributed to the Society of Telegraph-Engineers and Electricians by Mr. Preece, although it must be confessed the difference remains unexplained. Again, as regards the question of earth conduction, it may be remembered that in 1875 Mr. James Graves, of Valentia, contributed to the society already referred to an important communication upon "variations due to earth-plates," and detailed the extraordinary difficulties that were experienced by him in reading from the mirrors attached to the Atlantic cables, by reason of variations and disturbances which produced a constantly irregular motion of the "spot."

A brief consideration of this phenomenon may not be out of place at the present time, and possibly it may be gathered from the results of some experiments that have been made that the disturbance complained of by Mr. Graves possesses a marked and distinctive character, and, first, as to the probable resistance introduced into a circuit by the earth's crust. The earth cannot be considered as a conductor of electricity, apart from the moisture held by it; it is evident, indeed, that the earth's capacity for conduction will be to a large extent proportional to the moisture so held. When, however, the wide expanse of moist earth that almost necessarily divides two earth-plates is considered, it is difficult to apprehend any appreciable resistance to exist between them; and yet that some resistance is offered by the earth will appear from the following experiments:—Two clean copper plates, about 18 in. square, were buried 20 ft. apart to a depth of 4 ft. in a soil of loam, overlying sandy gravel. The earth plate electrolysis current steadily fell from first maximum to a point at which it was very weak, and then remained constant. Across and midway between the two plates shallow trenches were dug, and were kept supplied with water for some hours, the ultimate result being that, by reason apparently of the diffusion of moisture and the reduction of resistance, the current force increased several degrees.

The apparatus used was a sensitive Thomson reflecting galvanometer of 700 ohms resistance, and the scale was twenty-seven feet distance from the galvanometer, so that a very slight variation of force in the galvanometer would be well represented by the movements of the "spot." In the further experiment two flat coils of No. 18 copper wire were buried upright about 18 in. below the surface, and 4 ft. apart. The electrolysis current at first equalled a deflection of 38 in. upon the scale, but after falling steadily came to a stand at 18 in. from zero, and remained constant. The ground over and around these upright coils was now thoroughly soaked with water, and two days were allowed for diffusion. A trench was then dug of the same dimensions either way as the coils, between and parallel to them; the trench was a foot wide at top and tapered at the bottom. The effect of this trench was to decrease the deflection by 8 in. A small piece of dry board was ledged across the trench at its centre, and a child was instructed to build a bridge or road of damp earth from side to side over the board. The instant contact was made by the damp earth across the board, the deflection went up with a bound, and every succeeding reduction of resistance by the addition of earth to the bridge was clearly visible in the movement of the "spot." By this bridge the deflection was permanently increased by three inches, but again fell off as the earthen bridge dried under the sun. The effect of filling in the trench was also rendered clearly apparent by the swinging of the "spot" and ultimate increase.

It would thus seem that the earth's crust presents a higher resistance to the passage of electricity than would at first sight appear; secondly, and perhaps of greater moment, as to the apparent variability of the earth's conduction. Reference has been made to difficulties experienced at Valentia in reading the mirror signals received from America, by reason of irregular variations of the "spot," and which seemed to emanate from the earth plate. In that instance the disturbances could not be eliminated

until *earth* was virtually made by means of the sheathing of the Atlantic cables, instead of by the ordinary earth plate method. It may be stated that precisely similar variations are to be observed upon any circuit of which the earth's crust forms a part, provided that the means of observation are sufficiently sensitive, and that the wire tested is free from the larger effects of leakage, induction, and earth current.

Perhaps the most natural explanation that suggests itself concerning these variations is that of earth-plate variation —*i. e.*, a variation of the actual force generated at the plates, or of their resist ance. In order to investigate the phenomenon from that point of view, the sensitive Thomson reflecting galvanometer was brought into use, and tests were made of a great number of combinations— simple and involved, new cells and old, pairs of similar and dissimilar metals —without once obtaining the slightest sign of the variation in question. In every case there was the usual electrolysis current, which steadily fell from a first deflection to a stationary minimum, and which by disconnecting the circuit, or by inserting heavy resistance, would temporarily increase; but nothing beyond that was noticeable. It was thought that in the case of an earth plate the deposited hydrogen might by some means be disturbed, and so vary the resultant force. To test this point the following experiment was made:—The ends of two clean copper wires were immersed in a jar of sand and water; in the centre of this cell was inserted a 1¼ in. glass tube, 3 ft. high, so that by keeping the tube filled with water there would be a circulation of the liquid up through the sand and around the wires, the idea being to effect a disturbance of hydrogen. No visible effect was produced, however, and it seemed clear the variation in point was not of simple earth-plate causation.

Another possible explanation of these variations suggested itself, namely, that the influence of slight earth currents upon the earth plates might produce an intermittent and changing state of polarisation. In order to investigate this point a No. 18 copper wire was erected and perfectly insulated, and extended from my house to a distance of 300 yards upon one side, and of 170 yards upon the other. The distant ends were terminated by means of large coils of the same wire, buried to a depth of about 6 ft. In my own garden similar *earths* were put in for use as might be required. With the Thomson reflecting galvanometer in circuit, whether upon the whole length of line, or upon the right or left sections, it was always necessary to shunt down the electrolysis current in order to bring the "spot" within the ten foot scale, and notwithstanding this reduction of current passing through the galvanometer coils, the variations under consideration were always present. This variation, this *constant* movement of the spot, was usually much greater in amplitude upon the 300 yards length than upon the 170 yards section. Why it was difficult to trace, but it may be added that a baker's oven, which was heated each day, lay directly in the line of the two *earths* of that section. Then, also, the amplitude of the variation altered very considerably one day with another, sometimes the swing of the "spot" being so much as eight feet from side to side, *i. e.*, four feet each side the zero. It was difficult to decide how the question of earth current causation should be attacked; the first experiment, however, afforded no trace of concurrency in the variations of the two sections of wire.

A further experiment was conducted with a view to question the effect of earth-current *directive* force upon the earth plates, and was arranged thus:—A circle 40 ft. in diameter was described, and the chief points of the compass carefully staked upon it. Two poles were sheathed with clean copper at their lower extremity, the copper being connected to the experimenting room by means of loose covered wires. The sheathed ends of the poles were driven into the moist earth to a depth of two feet. Starting with the poles at opposite points —N and S—upon the circle a careful observation was made, and the slight but clearly discernible oscillations of the "spot" were noted. Similar observations were repeatedly made with the poles at each pair of opposite points, but without leading to any trace of directive effect, both variation and amplitude being pretty much the same all round the circle, and the idea of earth-current connection was, for the time being, given up. The

fact had, however, been elicited that these variations were in a slight degree obtainable from *earths* that were comparatively near one another, although when very near the effect upon the apparatus ceased. Prior to dismantling the arrangement the following experiment was tried:—Two pairs of earth plates were buried thirty feet apart, the respective plates of each pair being three feet apart. Upon joining either pair through the galvanometer no variation effect was observable, but when either plate of one pair was joined through the galvanometer to either plate of the other pair slight oscillations of the spot became apparent, indicating, it would seem, that at least some extent of the earth crust between a pair of earth plates is necessary in order to obtain these effects.

The remarks submitted here are not intended as a solution of this phenomenon, for it will be apparent that many important experiments await trial; but it is thought that the importance of the subject in its relation to long-distance telephony, and to the more sensitive systems of telegraphy, is such as to deserve a larger share of attention than it has hitherto received, and, further, that these results, which seem to point to a variation in the conducting power of the earth itself—locally, perhaps—warrant a more thorough and continued course of investigation than is within my own reach. It would be of interest also to know if and how far this variation is related to the sound disturbances heard from a buried microphone.

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## ON THE ENERGY OF FUEL IN LOCOMOTIVE ENGINES.

By GRANVILLE CARLYLE CUNINGHAM, M. Inst. C. E.

Selected Papers of the Institution of Civil Engineers.

The object of this paper and of the accompanying table, is to show, by data obtained from different railway companies, what is the amount of fuel consumed per unit of work done by locomotive engines; how this consumption varies in different lines of railways; and how the energy of the fuel utilized compares with the full energy, in other words, how much of the energy is used, and how much lost.

The consumption of fuel per unit of work, that is, per ton weight moved one mile, is perhaps the most certain and reliable scale by which the capacity of a railway for doing work can be measured, and compared on the same scale with another railway. Any estimate based upon cost is misleading, since the price of labor, fuel, and everything that enters into the working of a railway, varies at different times and in different places. It might thus happen that a line showing a large cost per train-mile, or per car-mile, was more economically and carefully worked, and better able to do the work for which it was constructed, than another showing a smaller cost per car-mile. The comparison plainly depends upon the cost of labor and material in the two localities, and is vitiated by the rise and fall of markets. No true comparison of the respective railways, or even of different periods of the same railway, can be made until such vitiating elements have been eliminated, and a basis arrived at which shall be common to each, and unaffected by any adventitious circumstances. In the consumption of fuel per unit of work there exists such a common basis of comparison, and one which demonstrates the capacity for doing work which the railway possesses. For the consumption of fuel is almost an absolute standard, varying only with the quality of the fuel used, and is not affected by any other uncontrollable circumstance. Thus, if on one line of railway the consumption per ton moved one mile is very much greater than on another, it is evident that on the former the gradients and curves, and such elements of resistance, must be more severe than on the latter; and that therefore the latter line is the better able to do its work, and can, other things being equal, do it more cheaply. Of course other circumstances may cause

an unusual consumption of fuel, such as severity of climate, inducing large evaporation and loss of heat; or badly-designed engines, resulting in waste of fuel. But even these are matters that can be controlled, because the first may be obviated by having the engine more thoroughly protected from the weather, and the second by improvements in the type of engine. With similar engines acting under not very dissimilar climatic influences, it remains that the consumption of fuel per unit of work may be taken as a certain index to the character of the railway.

In preparing the table which accompanies this paper, considerable difficulty has been experienced in arriving at the requisite data. The published annual reports seldom give the information in the direct manner in which it is required; but all the figures made use of have been drawn either from the published reports, or from information obtained directly from the railway officials.

On the Canada Southern Railway, where the consumption of fuel is lower than on any of the other lines, the gradients and curvature are very light. The main line of this railway extends through the southern part of the Province of Ontario in Canada, from Fort Erie on the Niagara River, where the International Bridge gives access to the State of New York, and opposite to the City of Buffalo, to Amherstburg on the Detroit River, separating Ontario from the State of Michigan. The Detroit River is crossed by ferry-boats, on which the carriages are taken over to Grosse Isle; from whence they run into Toledo (where connection is made with the Wabash railway system), or into Detroit (where connection is made with the Michigan Central system), over the Toledo, Canada Southern and Detroit Railway. The distance from Fort Erie to Amherstburg is 229 miles, and throughout there is no gradient steeper than 15 feet to the mile (1 in 352), and the alignment is remarkably free from curves. On the western portion of the line, the distance from St. Clair Junction to Amherstburg, 107 miles, is made up of two straight lengths of 53 and 54 miles, joined by a light curve. The same gradient is maintained on the Toledo, Canada Southern and Detroit Railway, and on the St. Clair branch of the main line. The only parts of the system on which steep gradients exist are the Erie and Niagara, and Michigan Midland lines; but on these the traffic is extremely small, and they aggregate only 45.28 miles in extent, as compared with 403.64 miles of the entire system. The locomotives used are of the Baldwin type, with two pairs of driving-wheels coupled, and weighing about 60,000 lbs. on the drivers.

The main line of the Michigan Central Railroad, which extends through the southern part of the State of Michigan from Detroit to Chicago, is 284.07 miles in length, but with branches and leased lines, it comprised 949.59 miles in 1881. The gradients on the main line and branches are considerably steeper than those on the Canada Southern, and in places reach 52 feet to the mile (1 in 100). The locomotives used are similar to those on the Canada Southern, and the fuel is also similar, being bituminous coal from Ohio.

The Lake Shore and Michigan Southern Railway extends along the southern shore of Lake Erie from Buffalo to Chicago, with branches to Detroit and other places. The total mileage of the system in 1880, including leased lines, was 1,177.67, and of this the length of main lines is 504.49 miles. The gradients of the main line are considerably easier than those of the Michigan Central, and nearly as good as those of the Canada Southern Railway. The engines and fuel are similar to those on the lines beforementioned.

The Hannibal and St. Joseph Railroad is in the State of Missouri. Its mileage in 1880 was 292.35. From the length of trains hauled, the gradients would seem to be steep.

In preparing the table in the Appendix, information has not always been obtainable from the printed reports in the exact form required. In these cases the method adopted for supplying the particulars has been as follows. The total amount of coal and wood (the latter turned into its equivalent in coal) consumed is noted. When the amount to be apportioned of the freight and passenger services respectively is not stated in the printed report, the total amount is divided into two portions in the ratio of the respective engines, mileage, and also in the ratio

of 26 to 34, being that in which the consumption of a passenger-engine, as determined by careful observation, stands to the consumption of a freight-engine. This, in the first instance gives the total amount of coal consumed in each service, including switching or shunting. In order to arrive at the amount consumed in moving freight-trains on the line, the total amount of engine mileage made in switching or shunting is noted, and this is divided into two portions, in the proportion in which the passenger-train mileage stands to the freight-train mileage, and the switching is thus allotted to the respective services. The coal consumed in the service is then calculated by allowing 70 miles per ton. and the quantity thus obtained is deducted from the total quantity apportioned to the freight service. This estimate of 70 miles switching per ton of coal consumed is taken from the observations of the Lake Shore and Michigan Southern Railway, extending over a number of years. It will be seen, therefore, that the results obtained are only close approximations to the absolutely true figures of this subject; but still they are sufficiently close to be valuable as comparisons.

The table shows that the coal consumed in passenger traffic is less on the Lake Shore line than on any of the others, being, 12.8 lbs per passenger-carriage mile. Taking the average weight of the cars composing the passenger train at 16 tons, this would give a consumption of 0.8 lb. per ton hauled 1 mile; at the same time it is interesting to note that there is a consumption of 1.16 lb. per passenger moved 1 mile. The very large consumption of fuel per ton moved 1 mile in the passenger service, as compared with the freight-service, is undoubtedly due to the much higher rate of speed of the former, as compared with the latter. Confirmation of this is found on considering the figures applicable to the Hannibal and St. Joseph line. There the consumption per ton-mile in the passenger-service is less than that of either the Canada Southern or Michigan Central, and only very little greater than that of the Lake Shore line; whereas the consumption per ton-mile in the freight service of the Hannibal and St. Joseph line is very much greater than any of the others, being more than double that of both the Canada Southern or Lake Shore lines. This apparent anomaly is explained by the fact that the speed of the passenger trains on the Hannibal and St. Joseph line is much less than that on any of the others under consideration.

The consumption of fuel in freight-service on the Canada Southern and Lake Shore lines is nearly the same, with a small fraction in favor of the former, while on both lines it is less than on the Michigan Central, or Hannibal and St. Joseph. The amount of fuel consumed in moving 1 ton gross weight (including the fuel consumed in shunting) is barely $2\frac{3}{4}$ ozs.—a quantity which is surprisingly small. This is on the two first-mentioned lines; while on the Michigan Central and Hannibal and St. Joseph lines it amounts to 4 ozs. and 6.4 ozs. respectively.

In the latter part of the Table the amount of coal consumed in the switching or shunting work of the freight service has been deducted, and that consumed in the work of moving freight-trains on the line of railway only dealt with, with a view of arriving at the quantity consumed in moving 1 ton weight 1 mile. The result arrived at is as follows: Canada Southern, 2.30 ozs.; Lake Shore, 2.38 ozs.; Michigan Central, 3.52 ozs.; and Hannibal and St. Joseph, 5.76 ozs.

Though it will surprise most people who have not paid particular attention to these questions, to learn that there is sufficient energy in a piece of coal weighing only 2.3 ozs. to move one ton weight one mile; yet the investigations would not be complete if it were not ascertained what is the total energy of the fuel; what portion of it is used, and what lost.

The units of heat (Fahrenheit) developed in the combustion of 1 lb. of coal are 14133,* and as the mechanical equivalent is 772 foot-pounds per unit, the combustion of 1 lb. of coal is equal to 10,910,676 foot-pounds, or 5455.3 foot tons (American).

On the Canada Southern Railway, the average of the whole line is equal to a gradient of 5 feet to the mile; this will make the resistance to haulage equal to 11 lbs. per ton, taking the resistance on the level at 9 lbs. per ton; therefore as much energy will be expended in hauling 1 ton 1 mile, as in lifting 11 lbs. 1 mile

* "A Manual of Rules, Tables, and Data, &c.," by D. K. Clark, M. Inst. C. E., p. 405.

APPENDIX.—TABLE SHOWING CONSUMPTION OF FUEL ON VARIOUS RAILWAYS.

| | Canada Southern | Michigan Central. | | Hannibal and St Joseph. | | Lake Shore and Michigan Central |
|---|---|---|---|---|---|---|
| | 1881. | 1879. | 1880. | 1879. | 1880. | 1880. |
| Total engine mileage (including shunting) | 3,749,701 | 7,697,051 | 7,690,051 | — | 1,995,739 | 13,586,207 |
| Passenger train-mileage | 987,237 | 1,693,098 | 1,865,258 | 414,118 | 410,368 | 2,549,081 |
| Passenger car-mileage | 4,196,466 | 8,499,352 | 10,333,529 | 2,190,243 | 2,239,970 | 16,060,832 |
| Average number of cars per passenger train | 4.25 | 5.02 | 5.54 | 5.28 | 5.45 | 6.30 |
| Number of passengers moved 1 mile | 40,917,987 | 93,232,430 | 115,523,789 | 21,545,368 | 19,925,041 | 176,148,767 |
| Average passengers per car | 9.75 | 10.96 | 11.18 | 9.83 | 8.89 | 10.96 |
| Freight train-mileage | 1,775,237 | 3,687,305 | 3,658,605 | 938,095 | 975,603 | 7,481,489 |
| Freight car-mileage | 56,915,859 | 88,384,701 | 88,491,897 | 15,715,882 | 16,864,202 | 283,588,545 |
| Average number of cars per freight train | 32.06 | 23.97 | 24.16 | 16.75 | 17.28 | 37.90 |
| Number of tons of freight moved 1 mile | 487,965,507 | 721,019,413 | 735,611,995 | 111,987,174 | 120,665,740 | 1,851,166,018 |
| Average load per freight car.....tons. | 8.57 | 8.166 | 8.31 | 7.13 | 7.15 | 6.52 |
| Total amount of coal consumed.....tons. | 127,270.5 | 280,160 | 303,971 | 69,990 | 76,898 | 502,320 |
| Tons of coal apportioned to passenger service | 38,072 | 75,250 | 84,078 | 15,190* | 17,491* | 102,837 |
| Pounds of coal consumed per passenger train-mile | 77.12 | 88.88 | 90.15 | 73.11 | 85.24 | 80.68 |
| Pounds of coal consumed per passenger car-mile | 18.14 | 17.70 | 16.27 | 13.84 | 15.63 | 12.80 |
| Pounds of coal consumed per ton moved 1 mile | 1.13 | 1.10 | 1 01 | 0.86 | 0.98 | 0.80 |
| Pounds of coal consumed per passenger moved 1 mile | 1.86 | 1.61 | 1.45 | 1.31 | 1.75 | 1.16 |
| Tons of coal apportioned to freight service | 89,198 | 204,910 | 219,893 | 54,800* | 59,407* | 399,483 |
| Pounds of coal consumed per freight train-mile | 100.49 | 111.17 | 120.20 | 116.83 | 121.77 | 106.78 |
| Pounds of coal consumed per freight car-mile | 3.13 | 4.64 | 4.97 | 6.97 | 7.04 | 2.81 |
| Pounds of coal consumed per ton of freight moved 1 mile | 0.367 | 0.57 | 0.60 | 0.98 | 0.99 | 0 43 |
| Pounds of coal consumed per ton of gross weight† | 0.168 | 0.25 | 0.27 | 0.40 | 0.41 | 0.17 |
| Average miles run by engines per ton of coal | 29.46 | 27.47 | 27.47 | — | 25.95 | 27.04 |
| Total expenses (exclude renewals and taxes).....$ | 2,550,223.11 | — | — | 1,223,421.97 | 1,304,590.08 | — |
| Passenger expenses (exclusive renewals and taxes).....$ | 584,148.13 | — | — | 414,150.20 | 439,295.75 | — |
| Passenger expenses per train-mile.....$ | 0.59.17 | — | — | 1.01 | 1.07 | 0.92.29 |
| Passenger expenses per car-mile.....cents. | 13.92 | — | — | 18.9 | 19.6 | 14.65 |
| Freight expenses.....$ | 1,966,074.98 | — | — | 809,271.77 | 865,294.33 | — |
| Freight expenses per train-mile.....$ | 1.1075 | — | — | 0 863 | 0.887 | 1.0767 |
| Freight expenses per car-mile.....cents. | 3.45 | — | — | 5.15 | 5.13 | 2.84 |
| Average expenses of tons of freight moved 1 mile...cents. | 0.40 | — | — | 0.72 | 0.72 | 0.43 |
| Coal consumed in freight shunting alone.....tons. | 9,025 | 22,698 | 20,945 | — | 6,122 | 35,282 |
| Coal consumed by freight-trains alone.....tons. | 80,173 | 182,212 | 198,948 | — | 53,285 | 364,201 |
| Coal consumed per freight train-mile .....lbs. | 90.32 | 98.8 | 108.7 | — | 109.23 | 97.36 |
| Coal consumed per freight car-mile.....lbs. | 2.81 | 4.12 | 4.5 | — | 6.32 | 2.57 |
| Coal consumed per ton of freight moved 1 mile.....lbs. | 0.32 | 0.50 | 0.54 | - | 0.88 | 0.39 |
| Coal consumed per gross ton moved 1 mile..... lbs. | 0.15 | 0.23 | 0.24 | — | 0.37 | 0.155 |

* These quantities are found from the value of fuel apportioned to the passenger and freight traffic in the Annual Report. † Weight of the cars is assumed at 10 tons each.

vertically. In other words, hauling 1 ton 1 mile requires an expenditure of energy equivalent to $5{,}280 \times 11 = 58{,}080$ foot-pounds, or 29.04 foot-tons.

But on the Canada Southern Railway, 1 ton is hauled 1 mile by the combustion of 0.15 lb. of coal, which quantity of coal therefore does work equivalent to raising 29.04 tons 1 foot. At the same rate 1 lb. of coal would raise 193.6 tons 1 foot vertically. But as shown above, the full energy of 1 lb. of coal is 5,455.3 foot-tons; therefore the full energy is to the work effected on the Canada Southern Railway as 100 is to 3.5, and consequently there is a loss of 96.5 per cent. of the energy of the fuel. Though the quantity, 2.3 ozs. of coal, seems extremely small to do the work of hauling 1 ton 1 mile, yet, if all the energy contained in the coal could be utilized and applied to doing work, it would haul 1 ton 28½ miles; while the quantity, 1.86 lb., consumed in moving a passenger 1 mile would, if fully utilized and applied to the transportation of freight, convey 1 ton 353 miles. Few passengers are aware of how much energy is required to make "fast time."

The speed of passenger trains on the Canada Southern Railway was from 35 to 40 miles per hour; on the Michigan Central and Lake Shore lines from 33 to 36 miles per hour; and on the Hannibal and St. Joseph line about 25 miles per hour. The speed of freight trains on all the lines was between 15 and 20 miles per hour.

The position of acting Chief Engineer, which the author until recently occupied on the Canada Southern Railway, enabled him to obtain the information in regard to gradients required to make the foregoing investigations; but the like information has not been obtainable for the other railways under consideration, and therefore it is not possible to say whether they waste more or less of the energy of the fuel consumed. A comparison on a similar basis with English railways would be interesting and valuable, but the necessary data do not seem to be available. These figures clearly indicate how much yet remains to be done in economizing the energy developed in the combustion of coal. An engine which wastes 96½ per cent. of the energy with which it is supplied cannot be called perfect.

The table also shows the cost of the service performed, worked out in a similar manner as the consumption of fuel.

## CORRESPONDENCE—KUTTER'S FORMULA.

*To the Editor of* VAN NOSTRAND'S MAGAZINE:

Mr. Flynn's criticism of my modification of Kutter's formula for pipes has just reached me. Mr. Flynn is quite correct. The formula as it stands in page 25 of the twenty-first edition of my pocketbook has an omission of $\sqrt{d}$. As I had originally framed it, it stood thus:

$$C = \frac{181 + \frac{.00281}{S}}{1 + \frac{.026}{\sqrt{d}}\left(.41.6 + \frac{.00281}{S}\right)}$$

Unfortunately the omission of the $\sqrt{d}$ escaped my observation in correcting the proofs of this twenty-first edition.

Taking the side cases which Mr. Flynn has worked out, a comparison of Kutter's formula and my modification of it for pipes, as corrected, stands thus:

| Diam. of pipe. | Slope 1 in 1. | Kutter. | Molesworth. |
|---|---|---|---|
| 6 in. | 40 | 71.50 | 71.48 |
| 6 in. | 1000 | 69.50 | 69.79 |
| 4 ft. | 400 | 117.00 | 117.00 |
| 4 ft. | 1000 | 116.5 | 116.55 |
| 8 ft. | 700 | 130.5 | 130.68 |
| 8 ft. | 2600 | 129.8 | 129.93 |

The two formulæ are thus far substantially identical in results though differing slightly in form. GUILFORD MOLESWORTH.

SIMLA, India, May 17, 1886.

## ENGINEERING NOTES.

A POCKET HELIOGRAPH.—A pocket heliograph or optic signaller has been brought out by Dr. E. Gavoy, and introduced into the French military telegraph staff by the Minister of War. It consists of two copper tubes of five centimetres in diameter, sliding one within the other. The upper tube carries a plane mirror, inclined at an angle, and throwing off the light of a lamp, or the sun reflected up to it from an adjustable mirror in the lower tube. The light thus thrown off passes along a short tube at right angles to the upper part of the main tube, and in doing so traverses two lenses, one plano-convex the other double convex. Between these two lenses is an adjustable shutter, by which the rays are occulted so as to make the signals. An oil lamp, with reflector to throw its rays on the lower mirror, is added to the apparatus in such a way that it shuts up within the lower tube under the lower mirror. A lunette to indicate the path of the rays through the air to the distant observers is also fitted to the top of the apparatus. According to trials recently made in the park of Versailles, the apparatus worked satisfactorily over distances of from 1000 to 1200 metres.

WOOD TURBINE WATER WHEELS.—In some portions of Europe, turbines constructed of wood and iron have been made to a limited extent, but the writer once saw a turbine con-

structed entirely of wood. The southern portion of the Appalachian range of mountains, in the United States, juts into the northern portion of those States bordering on the Gulf of Mexico, and the western portion of the States forming the Atlantic coast. This region consists of a plateau broken up by high mountains, and is a most fertile country, sparsely inhabited by a primitive people, descended from the early English settlers in the southern portion of the American colonies; but this country possesses no navigable rivers, and has not been traversed by the railroad, and has therefore been isolated from the rest of the world. Words and forms of expression are there used which have been obsolete in the English language for at least a century. The writer, while on a horseback trip among these mountains in 1881, saw a man, near one of the little grain mills, working on what appeared to be a foundry pattern. On asking a few questions, it was learned that this miller, while on a trip to a manufacturing town near to the sea shore, saw a water-wheel taken up for repairs in one of the mills, and remembered enough to make a Boyden wheel, carving it from a sycamore log.

The opening of the canal, which has been in process of excavation for the past five years for the purpose of draining Lake Copais, was celebrated on Saturday last in presence of the French Minister and numerous distinguished persons from Athens. Lake Copais, which is situated near Thebes, in Bœotia, covers an area of over 60,000 acres, or nearly 100 square miles. The French Company which has been engaged in carrying out the enterprise is now so far advanced with its work that two-thirds of the waters of the lake are expected to be drawn off within the next two or three months. Hitherto this inland sea has been chiefly remarkable for the malaria and fevers regularly prevailing on its shores during the hot season. By its drainage, not only will this evil be permanently removed, but Greece will add to her territory many thousands of acres of arable soil of the greatest fertility. The lake is fed by the rivers coming down from Mount Parnassus, whose waters are hereafter to be employed, by help of a new system of canals, in irrigating the surrounding country.

Railway Tunnels in Russia.—Although Russia has built over 15,000 miles of railway, the longest tunnel she has had to construct up to this year has only been 700 yards long. On this account the vote last week by the State Council of £700,000 to construct a tunnel three miles long on the Suram loop line, possesses for Russia extreme importance. To all intents and purposes her railway engineers are practically ignorant of tunnel making, and to carry out the Suram undertaking the advice of foreign experts has had to be sought. Simultaneously with this, a tunnel 1400 yards long will be taken in hand on the Novorossisk Railway, in the Kuban region of Cis-Caucasia. This will be twice as long as any existing tunnel in Russia. For the most part the tunnels already made are on the Lozova-Sebastopol, Warsaw, Ivangorod-Dombrova and Transcaucasian railways—that is to say, all the outskirts of Great Russia proper, being situated in Poland, the Crimea, and the Caucasus. Elsewhere, there are no tunnels at all, and but very rarely bridges across railway cuttings. Probably in the metropolitan area there are more bridges and tunnels than in the whole Russian empire. Thanks to this circumstance Russia is able to move some of her military and naval resources about in a manner hardly appreciated by English strategists and statesmen. Thus, during the Turkish war, she took steamers off the River Neva, placed them on trucks and sent them by rail with the greatest facility, to the Black Sea and the Danube. Only a few months ago, she shifted at a stroke fifty torpedo boats in this manner from the Baltic to the Black Sea. Yet in spite of all this, there were actually certain feather-brained generals at the War Office last year, who proposed during the war scare, that England should seize Batoum and the Transcaucasian Railway and send across the latter steamers in segments, to be fitted together at Baku to fight the hundreds of steamers Russia already possesses in the Caspian and Volga, and the scores she could have sent at once, ready made and fit for action, by railway in the manner we have described, from the Neva and other rivers to the Volga! Perhaps the War Office is a little bit wiser now and has pigeonholed for good a plan which would have exposed every English steamer placed on the Caspian to a ridiculously hopeless contest. It may be noted that now the Russian railways have commenced spreading in the Caucasus, a deal of tunnelling will be encountered. On the direct St. Petersburg-Tiflis line, at present broken by a short gap from Vladikavkaz to Tiflis, a tunnel eight miles long has been planned for years, piercing the main bridge of the Caucasus. There is hardly a doubt that this will be taken in hand after the completion of the Suram tunnel.

## IRON AND STEEL NOTES.

A New Process of Round Forgings.—Mr. George H. Simonds, of Fitchburg, U.S.A., has invented a machine for the purpose of forging iron or steel in any form which can be turned. This involves an entirely new method of working iron. Instead of being hammered or rolled to the desired form, the mass of red-hot metal is placed in a groove in two plates which are moved in reverse directions; the grooves are in primitive form at the places where the iron first enters between the plates, and along its course these grooves become more closely in conformity to the shape which is given to the finished piece, which is twisted into shape. The process is applied with success to the manufacture of conical shot, forged out of steel, the British Government having given an order for 500,000 shot, which are being made by the English representative. This process is applied to the manufacture of any small iron or steel pieces of turned form.

The Direct Production of Steel.—The direct production of steel from the ore is a subject which has long attracted the attention of metallurgists and others, and several at-

tempts have been made to solve the problem. The latest proposition in this connection is that of Mr. James J. Shedlock, of 9 Gracechurch street, London, which comes to us with a degree of individuality and hopefulness not usually met with in such inventions, and this by reason of its being a distinct departure from previous practice. The principles involved in Mr. Shedlock's process consist in the use of reducing gases produced by the decomposition of steam in conjunction with a bath of molten metal, which he employs to take up the metals as they are reduced from their combinations. The problem of thus releasing metals from their ores without liquefying the matrix, and therefore without using fluxes and resorting to high temperatures, has had long and careful study at the hands of Mr. Shedlock, who has been working at it for the past twelve years. Having proved it over a wide range of metals, he has at length brought it to that point at which demonstration on a practical commercial scale need be no longer delayed. To this end extensive premises have been taken at Blackwall, and machinery and smelting apparatus put up there for carrying out the process, and which we recently inspected. The works have a frontage of 190 feet on the River Thames, and railway communication is close at hand. The apparatus is of exceedingly simple character, and the plant now laid down is calculated to smelt about 25 tons of ore per day; but there is ample room for more than quadrupling the present appliances and rate of output.

Mr. Shedlock's method of treating ores for the separation of their metals is carried into effect by passing the ore in a finely divided state through a bath of molten metal maintained at the temperature necessary to insure its combination with any free metal contained in the ore. But as most ores contain metals associated or in combination with the metalloids, it is necessary to decompose such compounds in order that the metals may be freed and in such a condition as to readily combine with the metallic bath.

This is accomplished by forcing streams of reducing gases through the bath of molten metal simultaneously with the pulverized ore, which is conveyed into the bath at one end by feeding apparatus, the action of which is so regulated as to work in concert with the supply of reducing gases. For the production of these gases, steam is passed through superheaters, the outlets of which communicate with gas producers, which produce carbonic oxide and hydrogen gases, which are conveyed from the producers by tubes into the bath of molten metal at the point of entry of the powdered ore.

In consequence of the affinity possessed by these gases for the metalloids, and also by reason of their high temperatures, the metallic compounds are decomposed and the volatile constituents of the ore are vaporized, which, with the earthy or non-reducible portions, by reason of their lesser specific gravity, rise to the surface of the bath of molten metal. The gases and vapors are conveyed through flues into chambers where those that are condensable are thrown down and collected, the permanent gases escaping into the chimney shaft, and the earthy matters being removed from the end of the bath opposite the feeding end by skimming. The metals as they accumulate in the bath overflow into receivers through spouts, the inner mouths of which are so much below the surface of the metal as to prevent any dross from passing over. The metals as they collect are run into ingots or bars.

In treating some ores, more particularly those containing the noble associated with the baser metals, it may be found desirable to refine those metals without removal from the bath. For this purpose atmospheric air raised to the required temperature is forced through the molten metals in the bath, its passage being retarded by an inclined cover, thereby causing agitation of the mass and subjection of the metals and metalloids to the oxidizing action of the heated air. The oxides and other combinations thus formed with the vapors and gases rise to the surface, and are conveyed by the flues to the condensing chambers, the refined metal being withdrawn from the bath and run into ingots. The superheaters, gas producers, and air heating chambers are inclosed in a firebrick structure, into which the heated products of combustion from the furnace enter and circulate, thus raising the temperature of the apparatus and its contents to the required degree.

The furnace gases then pass into the flues surrounding the bath containing the molten metals, eventually escaping into the chimney shaft. According to Mr. Shedlock, there are no exceptions to the ores which may be manipulated by his invention, the most refractory as well as the most easily reduced being successfully treated by its means. The ores of iron, when subjected to the process for the extraction of that metal, are stated to be most readily reduced, and its direct conversion at one operation into the different carbides of iron, varying from the softest cast iron to the mildest steel, easily accomplished; at the same time, all deleterious impurities are said to be effectually removed. The ores of zinc are also readily treated by this process as a continuous operation, the ore being fed into the apparatus, and the metal as it is distilled over passing away through the flues into the chambers, where it is condensed and collected. Should the process be as successful an operation on the large scale as is anticipated, we may expect an increased supply of gold, as by its means the most refractory ores of gold may be treated. By the ordinary system of separating gold from its ores, it is acknowledged that not much more than 50 per cent. of the gold present is recovered. The details of the invention, as well as those of the apparatus by which it is to be carried into practical effect, have been carefully thought out, and the reasonableness of the modus operandi gives every hope of its commercial success. The works will shortly be running, and after some hundred tons or so of stuff have been put through—which Mr. Shedlock very properly holds is the only fair test of the capabilities of his invention—we shall report progress, in the meantime wishing the process every success.—*Iron.*

## RAILWAY NOTES.

Messrs. Bolckow, Vaughan and Co., Middlesbrough, have secured an order for nearly 10,000 tons of steel rails for the Swedish and Norwegian Railway Company. This, with the rails on hand, is sufficient to complete the 200 kilometres of the company's line from the great iron mountain of Gellivara to the port of Lulea. This iron ore in inexhaustible quantities contains 70 per cent. of metallic iron. The company hopes to lay this section of the line this year, and it is taking delivery of 1000 tons of rails per fortnight.

Swedish Railways.—The length of the railways of Sweden at the end of 1885 was nearly 3,000 miles, half of which belonged to the state, the total gross receipts being £2,110,000, or £700 per mile, £1,100,000 of which were earned by the state lines. Concessions were granted to private companies for 95 miles of new lines, whilst 180 miles of private and 10 miles of state railway were opened for traffic during the year.

Canadian Railway Progress.—The following percentages of increase in the railway system of Canada during the last ten years indicate also very clearly the development of the country during that period. The miles of completed railway have in ten years increased 118 per cent., the amount of capital invested has increased 48 per cent., the gross earnings show an increase of 66 per cent., and the net earnings an increase of 130 per cent. The number of passengers carried increased 76 per cent., the amount of freight 130 per cent., and the train mileage 70 per cent.

The St. Gothard Tunnel line was opened for traffic on the 1st of January, 1882. Since then Germany has increased the value of her exports to Italy from 66,000,000f. to 110,000,000f., and to Spain—by Genoa—from 51,344,000f. to 86,679,000f. As for Switzerland, in 1881 her exports to Italy were valued at 37,000,000f.; they have now risen to over 75,000,000f. Italy has benefitted even more. Her exports to Switzerland, Germany, and Belgium have risen by leaps and bounds, and the commerce of the port of Genoa in particular has increased since the St. Gothard line was opened by 50 per cent. What Italy has gained France has lost. Merchandise from the North wishing to reach the Mediterranean is being more and more sent to Genoa instead of Marseilles The former port, thanks to the St Gothard line, has the advantage in distance over Marseilles as follows:—From Antwerp, 76 kilometres; Ostend 34; Charleroi, 66; Brussels, 76; Namur, 127; Amsterdam, 139; Utrecht, 162; Cologne, 259.

English capitalists are looking to Holland as a field for railway enterprise. Holland has an area of 12,680 square miles, and a population of some 4,300,000 inhabitants, but possesses only about 1100 miles of railway. The waterway system has hitherto provided sufficient means of locomotion to meet the wants of trade and commerce. A company called the English-Dutch Light Railways Company proposes to utilize the existing public roads for light railways or tramways, for goods as well as passenger business, and for working by steam. The gauge proposed is 3ft. 6in., and the first line to be built is from Breda—a junction for Rotterdam, the Hague, and Amsterdam—to Oudenbosch and to the frontier of Belgium—a distance of about 28 miles. The Société des Chemins de Fer Vicinaux has arranged to make a similar line from Antwerp to the frontier, simultaneously with this one, so that there will be uninterrupted communication between Breda and Antwerp. The second line is proposed to run from Druten through Wychen, passing through many thriving towns and communes to Gennep, a distance of about 29 miles.

## ORDNANCE AND NAVAL.

Our New Navy.—It is understood that Secretary Whitney will in a few days invite proposals for building the four steel war vessels recently authorized by Congress. One of these vessels is to be 800, one 1,700, and two 4,000 tons each. The Secretary has been severely criticised for purchasing abroad the plans of the 4,000-ton steel vessel lately built by Armstrong for the Japanese Government, but all American shipbuilders who have examined these plans cordially approve them The vessel in question combines the most advanced ideas of naval architecture, the results of several years of actual experiment, and the vessel is a complete success, having made within a small fraction of nineteen knots at sea. The plans of this vessel have been open to the examination of all American shipbuilders, and it is unanimously agreed that the Secretary did a wise act in purchasing the plans and placing them on exhibition for the benefit of our shipbuilders. It is probable that these plans will be adopted in the construction of the four cruisers, and that the two 4,000-ton vessels will be exact copies of the ship built by Armstrong for the Japanese Government. The Acting-Secretary of the Treasury has sent to the Senate a letter from the Secretary of the Navy submitting a request for an appropriation of $186,908 to complete the three steel cruisers, Chicago, Boston, and Atlanta, and to pay the amount due on the dispatch boat Dolphin. He says work on the vessels in course of construction at Mr. Roach's yards must be discontinued, and the final payment on the Dolphin can not be made, thus causing much embarrassment to the Government and Mr. Roach's assignees.—*Bulletin.*

Tank Steamers on the Tyne.—According to an authoritative statement in the *Newcastle Chronicle*, "the workmen at Messrs. Hawthorn & Leslie's shipyard, at Hepburn, will be shortly engaged both day and night, arrangements having been completed for making five vessels into petrolum tank steamers," in consequence of which "a number of the unemployed in Hebburn and Jarrow will probably be restarted." This is an eminently satisfactory announcement, and we trust that now a commencement has been made in a direction persistently advocated since 1883, we shall hear of other proofs of similar activity in the north.

It may be remembered that on the return of the traveler, Mr. Charles Marvin, from Baku, in 1883, he drew attention in his "Petroleum Industry of Southern Russia" to the astonishing success of the tank steamers in the Caspian Sea, and urged that English shipowners should apply to the ocean generally what Messrs Nobel had introduced on the Caspian and Volga. His arguments seemed to us sound, and repeatedly, during the depressed period of last year, we recommended the matter to English shipowners, particularly as the revolution in the mode of transport involved a vast amount of activity, of which a rough estimate could be formed from the single fact that in the Caspian alone the petroleum trade had called into existence 80 new tank steamers for a supply not one-sixth as large as that of the United States. In the interests of the very large number of men out of employ, it is a pity, perhaps, that the task of constructing tank steamers for the Atlantic petroleum trade was not commenced earlier; but, all the same, we are very glad English shipowners have thoroughly assimilated the idea at last. Speaking at a lecture on petroleum before the Blackheath and Lewisham Scientific Society a fortnight ago, Mr. Martell, chief surveyor of Lloyd's, said that he was "almost daily having inquiries addressed to him by shipowners and others with reference to these tank steamers." We mention this because it is only now that English shipbuilders are admitting, by the construction of these steamers, that this two years' advocacy of their interests was not misplaced, and because we wish them to realize that the American petroleum trade will want at least a couple of hundred of these steamers before the requirements of bulk transport are in any way properly satisfied.

THE NORDENFELT GUN.—A highly interesting and important series of experiments was recently carried out at Dartford with several patterns of the Nordenfelt gun. The experiments were divided into two parts, the first comprising trials with single and multiple-barrel rifle-calibre guns and the two-barrel 1-inch gun, whilst the second included quick-firing guns. Experiment I. was with a single-barrel rifle-calibre gun, mounted on a field carriage, and which was fired for 30 seconds, 80 rounds being got off in that time. Experiment II. was with the 3-barrel rifle-calibre gun, also mounted on a field carriage. At the start, only a couple of rounds were got off when a hitch occurred, and on examination it was found that the cartridges were supplied of a wrong pattern for the gun. Nothing daunted, Mr. Nordenfelt had a second gun run up, from which 87 rounds were got off in 20 seconds. Attention was then turned to the 5-barrel rifle-calibre gun mounted on an infantry carriage, with which two hoppers containing 100 rounds were fired in 13 seconds. The same gun was then fired for 30 seconds, during which 265 rounds were got off. The 10-barrel rifle-calibre gun, mounted on a naval carriage, then fired 200 rounds in 13 seconds, after which it was fired for 30 seconds, during which 400 rounds were got off. Experiment V. was with a 5-barrel rifle-calibre gun mounted on a carriage, intended for use in the tops. The gun was placed on a high bank commanding the range, and fired with a depression of 55°, 200 rounds being got off in 13 seconds. The sixth and last experiment of the first series was with a 2-barrel 1-inch gun mounted on a naval carriage. With this gun 20 rounds were fired in 5½ seconds, after which it was fired for 30 seconds, including the time for changing the hoppers, when 76 rounds were got off. The proceedings were then varied by drill by a detachment of the Central London Rangers Machine Gun Club, under the command of Lieutenant Fielder, with a 5-barrel Nordenfelt gun on an infantry carriage, at which point proceedings were stayed for luncheon, which, after the heat, dust and smoke, was by no means unappreciated.

On resuming, experiments for penetration were commenced with quick-firing shell guns, the first tried being a 1-inch gun, firing a solid steel shot with a hardened point—not chilled, but tempered just as a chisel or a turning-tool is tempered. The Nordenfelt shot, as also the shell, are all turned out of the solid, and have their points thus hardened. The 1-inch gun was laid against a 1-inch wrought-iron plate, the range in all cases being 100 feet The shot went clean through the plate and wood backing. The 1½-inch 2-pounder shell gun was then fired with a solid projectile against three 1-in. wrought-iron plates clamped together, the projectile embedding itself in the three plates, and showing a bulge at the back of the rear plate. A second round was fired from this gun, with similar results. The 6-pounder shell gun was then laid against five 1-inch wrought-iron plates leaning against each other at a slight angle against the wood backing, with slight spaces between them, that between the third and fourth plates being 1 inch. Taking the spaces and angle into consideration, the plates may be said to represent a 6-inch target, and through this and the timber backing the shot passed splendidly, the plates being held together after the shot by the burr passing from the rear of each plate to the face of the next. This was distinctly seen in the 1-inch space between the third and fourth plates Tests for rapidity of fire were then made with the shell guns, the first tried being the 3-pounder shell gun mounted on a field non-recoil carriage. With this gun three rounds were first fired slowly, in order to show the working of the carriage, which did the most effectually, after which six rounds were fired in 13½ seconds for rapidity and accuracy of fire. The six-pounder shell gun, mounted on a recoil carriage, then fired 6 rounds in 15 seconds, after which the 1½-inch shell gun, mounted on a naval non-recoil carriage, fired 6 rounds in 17 seconds.

The visitors then witnessed drill by a detachment of the 2d Battalion of the Grenadier Guards, under Captain Lloyd, with a Nordenfelt 5-barrel machine gun mounted on an infantry carriage. The drill was very good, and afterwards the gun was brought up at the double over rough ground to the range, where volley firing and single-firing was performed with an excellence that elicited the approval of

all. The third and final drill was by a detachment of the 10th Hussars, under Major Wilson, with a Nordenfelt 5-barrel rifle-calibre machine gun, mounted on an improved Beresford galloping carriage. Some very effective work was done with this carriage, which was put through some heavy drill with excellent results, and was afterwards run up over a sharp bank on to the range and fired. Mountings for machine guns for camels and mules were shown, the latter animals being packed and satisfactorily put through their paces. The day's proceedings were in every way successful, and demonstrated the variety, efficiency and usefulness of the Nordenfelt machine gun, against which torpedo boats would stand but a poor chance.

## BOOK NOTICES.

THE NAVAL BRIGADE, AND OPERATIONS ASHORE; A HAND-BOOK FOR FIELD SERVICE, PREPARED FROM OFFICIAL AND STANDARD AUTHORITIES. By H. K. GILMAN, First Lieut. U. S. M. C. Naval Professional Papers, No. 20. 16mo, leather tuck.

In the May number we quoted, under "Publications Received," the titles of the Naval Professional Papers from No. 1 to 18, inclusive. The above title is that of No. 20 in this same series, No. 19, for some reason, not having made its appearance. The present volume is a nicely gotten up manual, bound in full leather, and evidently intended to be carried in the pocket as a reference book. It is mainly a compilation from various writers, giving in a concise form such military principles and general information as naval officers would naturally require when officiating ashore with an armed force. As the book is issued by the Navy Department, it is to be assumed that all the instruction and information given bears official sanction, and it is therefore quite superfluous to say that the book is a valuable one; for inasmuch as the work is a gathering together in a concise and compact form all the instructions required for officers of the Marine Corps, it is assumed at once that to them, at least, it is almost invaluable. We can say, however, that it might have been better printed, and the table of errata shows inexcusable carelessness in the proof reading.

STEAM-HEATING PROBLEMS; OR QUESTIONS, ANSWERS, AND DESCRIPTIONS RELATING TO STEAM-HEATING AND STEAM-FITTING. From *The Sanitary Engineer*. With one hundred and nine illustrations. New York: *The Sanitary Engineer*. 1886. 1 large 8vo volume, handsomely bound in cloth. Price, post paid, $3.00.

This volume of 233 pages, just out from the *Sanitary Engineer* press, cannot fail to find at once a large number of friends who have been vainly on the look out for an American book of this kind. The book is eminently serviceable to all those who design, construct, and have charge of steam-heating apparatus; but it will also prove useful to civil, mechanical, and sanitary engineers, to architects and to all manufacturers who own a steam boiler for power purposes. Incidentally, we notice a number of other questions come in for discussion, such as contrivances for raising water automatically in high buildings, heating water in large tanks, and for large institutions, coating water pipes, testing gas pipes, and methods of gas-fitting, probably because the ordinary steam-fitter or mechanic is frequently called upon to do such work, not strictly coming under the title "Steam-heating Problems." Again, we find questions on ventilation, on moisture on walls, etc., on hot-water heating, discussed at length, we presume because questions of heating and ventilation are closely connected, and cannot always be treated separately, and because hot-water heating differs but little in arrangement from steam-heating.

The steam-heating problems presented are numerous, and the solutions and answers are of practical value, and often of great interest. The subjects discussed embrace steam boilers, calculation of heating surfaces, radiators and heaters, piping and filling, cutting nipples, bending pipes, steam, exhaust steam, superheating steam, and a large variety of questions under the headings "Miscellaneous" and "Miscellaneous Questions." The volume also contains illustrated descriptions of steam-heating plants in several large New York office-buildings, of warming and ventilating arrangements in several churches and theatres, etc.

The book is largely made up from the "Queries and Replies" which have formed a special feature of the volumes of the *Sanitary Engineer*. It forms a companion volume to the "Plumbing and House-Draining Problems" issued some time ago by the same publishers.

PHOTO-MICROGRAPHY. By I. H. JENNINGS. London: Piper & Carter.

This is one of the useful photographic handy books issued by the firm of Piper & Carter, and treats of a subject which has much to interest the scientific amateur who possesses a microscope and "dabbles" in photography. Photo-micrography is a very useful art, for, amongst other reasons, it enables a lecturer to exhibit in an enlarged form exactly what has been seen under the microscope. Mr. Jennings gives much valuable information in this handbook, and his remarks on microscopical apparatus generally will be very useful to the beginner. There are so many wretched specimens of workmanship in the market sold as microscopes by persons who are opticians only in name, that Mr. Jennings thinks it necessary to caution beginners who want a microscope for real work against purchasing an instrument from any "but an optician of reputation." That may be good advice; but the novice who is ignorant of the methods of testing a microscope, is not likely to be acquainted with the reputations of opticians, and he had much better obtain the services of a skilled microscopist in choosing his instruments—that is, where any large sum of money is to change hands. The best-known English firms all sell really good microscopes at a moderate figure now, and the beginner, even if his purse is a deep one, will act wisely by commencing operations with one of the lower-priced instruments. In his introduction, Mr. Jennings says that a

"photo-micrograph allows no room for play of the imagination; it simply shows how a given object appeared at the time the observation was made"; but we venture to think that a great deal depends on the skill of the operator, both as a microscopist and a photographer, for certainly all photo-micrographs do not impart the same appearance to identical objects. Mr Jennings means, of course, when the operator is skilled in both branches, and he explains at some length that to produce creditable photo-micrographs, it is necessary, first of all, to be a skillful microscopist; but being that he should also have had, not some, but a good deal of experience in photography. There is, however, no reason why anyone possessed of average intelligence should not become a first class producer of photo-micrographs, and amongst the ranks of what are called scientific workers there are many who stand in the front rank as photo-micrographers. Like most other arts, experience is required, for we learn more by failures than by successes; but, so far as a text-book can help, nothing better can be desired than this little work by Mr. Jennings, which contains a chapter on the methods of preparing bacteria by Dr. R. L. Maddox, M. D. It may interest readers to know that Mr. Jennings recommends rapid dry-plates for photo-micography, provided they are prepared with good, hard gelatine. His book is usefully illustrated, and will be found to contain all needful information.

ELECTRICAL TRANSMISSION OF ENERGY, AND ITS TRANSFORMATION, SUBDIVISION, AND DISTRIBUTION. By GISBERT KAPP, C. E. London: Whittaker & Co. (Second notice.)

The author of this book leads his readers so gradually from the consideration of elementary principles to the clear statement of the conditions of successful solution of the most important practical problems, that the treatise will be of great value to students who are not yet expert in electrical work.

The author's estimate of the magnitude of the general problem is expressed in his introductory chapter, which we herewith append:

"The transmission of energy and its transformation is the fundamental problem of mechanical engineering. No piece of mechanism yet devised is able to create energy, but all mechanism has for its object the transmission and transformation for useful purposes, of energy already existing in nature in a more or less inconvenient form. The more perfect our mechanical appliances, the better are they fitted to direct the forces of nature to do useful work; and in this sense the electric transmission of energy must be regarded simply as an improvement on purely mechanical methods already existing. But it is something more. It not only improves mechanical methods, but extends the field for their application, inasmuch as it can, in many instances, reach nearer to the sources of power than any mechanical means.

"The most important natural sources of power are fuel, wind and water. As regards the first-named, electrical transmission can hardly be considered of any great importance for the purpose of reaching the source of power, for fuel, especially in its most useful form of coal, is so easily portable, that in most cases it is more convenient to carry the fuel to the place where the energy is required than to transform it into energy where found and transport the energy to the place of application. It has been suggested to erect large generating stations for electricity close to the pit's mouth, and work the dynamos by steam power obtained from the small coal which is not worth being carried by rail. The current generated could then be sent along wires to neighboring towns, and thus the energy contained even in the refuse of our coal fields could be utilized. As yet, this suggestion has not been carried into practice, except on a very limited scale, namely, in providing motive power for underground railways in coal mines.

The other two great natural forces, wind and water, especially the latter, offer a larger field for the application of electricity. Water power is only portable in a very limited sense. The great cost of channels, and the difficulty of providing elevated reservoirs close to those places where the power would be of greatest use, compels us in most cases to establish our factories close to natural waterfalls; in other words, we cannot carry water power to the work, but we must take the work to where the water power is. Where that is impossible or ineonvenient, the power cannot be directly utilized. It is in these cases that electrical transmission of power is of greatest value, inasmuch as it enables us to get at many sources of energy which would otherwise be wasted. The amount of energy contained in waterfalls all over the world is enormous. To cite only one or two cases. According to Herr Japing, the hourly weight of water falling in the Niagara is one hundred million tons, representing about sixteen million horse-power, and the total production of coal in the world would just about suffice to pump the water back again. M. Chretein, a French engineer, has, in a paper read at the Paris Electrical Exhibition in 1881, given the total water power in France as seventeen million horse-power, and has suggested that if by electric transmission only a part of this vast amount of energy were made available for useful purposes, an enormous economy in the consumption of fuel in France would be effected, and, at the same time, the hydraulic works necessary would also have the beneficial result of preventing, or at least mitigating droughts and inundations. This suggestion has already borne fruit, although only on a small scale. Near Bienne, in Switzerland, there is a waterfall representing an energy of several thousand horse-power. A small portion of this power is utilized by a turbine, which works a generating dynamo. The current is conveyed by an overhead line, consisting of a pair of copper wires (270 mills diameter) to Bienne, a distance of about a mile, where it works two electric motors; one in a mill where silver is rolled, and where the power required is very variable; the other in a watch factory, where, on account of the delicate nature of the work, an absolutely constant speed is required. The installation has now been at work with perfect success for over two years.

Another instance of electric transmission in connection with water power is the electric railway at Portrush, in Ireland, where the energy of a waterfall is, by means of a turbine and dynamo converted into electrical energy, which is conveyed to the line and along the rails into the motor of the car. There it is reconverted into mechanical energy, and utilized in propelling the car. Examples of this class might be multiplied, but these two will suffice to show that a practical beginning has already been made in the application of electricity for the purpose of reaching some sources of energy which would otherwise be lost. If progress in this direction has not been as fast as might be desired, the reason lies in this that installations of this kind are necessarily of some magnitude, and cannot be undertaken as mere experiments. If a small installation of electric lighting were to turn out a failure in any particular case, the loss to the contractor would not be so very serious. The dynamo, the wire and the lamps have all their fixed market value, and if they have to be removed from one installation, they can be utilized to another. Not so with the transmission of energy from some hitherto inaccessible source. The dynamo and the motor have to be built specially for each particular case, and the probability that they can be used elsewhere is small. The line and supports are expensive items, which have only value in that particular locality where they have been erected, and the works necessary for transforming the crude energy of nature so as to be applied for driving the generating dynamo have also only a local value. In such cases the installation must be a complete success, or else most of the plant and work is a dead loss; and it is but natural that capitalists shrink from rushing into enterprises as long as there is the least taint of an experimental nature about them.

Another reason which has, in England, at least, operated to delay the electric transmission of energy from natural and inaccessible sources to more convenient places, is that in this country coal is cheap and water power scarce. In France the case is different, and accordingly we find that the first experiments on a large scale have been undertaken there. Although it is quit incorrect to say, as is frequently stated in French papers, that M. Marcel Deprez has invented the electric transmission of energy, or has even invented any special system by which the electric transmission of energy is made practicable, it must be admitted that he has had the courage of his opinion, and has been the first to demonstrate that energy can be transmitted electrically over long distances. All scientists have long been agreed on the necessity of employing for long distance transmission currents of high electromotive force, but M. Marcel Deprez was the first to carry this into practice.

Broadly speaking, there are two purposes for which the electric transmission of energy is of great value. The one comprises all cases where, as has been shown above, hitherto inaccessible sources of natural energy are by its means rendered accessible, and the other comprises all those cases where the source of energy itself is accessible, but where it is desired to distribute it to a number of independent small working centers. In the first case we have to transmit a large amount of energy, so to speak, in one lump from the distant source to the place of operation; and, in the second case, we have to split up the energy of a source close at hand into a number of small fragments, and distribute them within a limited area to do useful work. In this case, electric transmission of energy comes into competition with the more mechanical means of belts, shafts, wire ropes, and pneumatic or hydraulic tubes, and the question whether one or the other of these systems is preferable, depends on the amount of energy transmitted, and the distance over which it is transmitted, as well as on many local circumstances. Electricity has the great advantage of being extremely portable, and capable of having its direction and intensity changed with greatest ease. No mechanical force can be detected in the conductor carrying the electrical energy such as appears during purely mechanical transmission with shafting, belts, wire ropes, or in pipes conveying steam, water or air. The conductor is clean, cold, does not move, and altogether appears inert. It can be bent, moved, or shifted in any manner, while transmitting many horse-power. It might be brought round sharp corners, and having little weight, it can be fixed with greater ease than any mechanical connection. It is thus possible to bring the energy into rooms and places awkwardly situated for mechanical transmission, and there is no noise, smell, dirt, or heat during the transit, nothing to burst or give way. The power is, moreover, under perfect control, and its application exceedingly elastic. The same circuit which may be tapped to give many horse-power can, at the same time, and as conveniently, be used to work a sewing machine, or other small domestic implement, and the power consumed at the generating dynamo is always in proportion to the power obtained from all the motors, so that there is no waste of energy if some of the motors are standing still or are working with less than their full load. In addition to these advantages, electrical distribution of energy has also the merit of being exceedingly economical. The commercial efficiency of dynamos and electro-motors seldom falls below 80 per cent., and is in many cases as high as 90 per cent., so that even if we make a liberal allowance for loss of energy in the conducting wires, 60 per cent. of the power of the prime mover at the generating station can be recovered from the motors distributed over a limited area. For instance, a steam-engine of 100 horse-power, driving a generating dynamo in the center of a two-mile circuit, could deliver an aggregate of 60 horse-power in as many separate points within that circuit. Apart from all considerations of nuisance and cost of attendance in the case of sixty separate small steam-engines placed throughout the district, which might be used instead of the sixty elecro-motors, it is evident that we can generate one hundred horse-power in one single engine at a far less cost of fuel than could be done in small engines, and although the double conversion necessitated by electrical distribution of energy entails some loss, there

is still a large margin in the general economy of the system.

In some cases it is found convenient to transmit the energy from the generating dynamo, not directly to the motors, but to interpose between the two a set of accumulators or secondary batteries. This is, in reality, an extension of the system, and has the double advantage of providing motive power even at those times when the generating dynamo is standing still, and also of giving to the motor a certain amount of portability. Electric transmission of power is thus actually carried beyond the limits of a fixed conductor, or is even effected without the aid of a conductor at all. As a case in point, may be cited the propulsion of street tramcars by means of secondary batteries. Here we have a charging station at some place near the line containing some prime mover and dynamos, the current from which is sent by a pair of cables to the secondary batteries in the car which are to be charged. This is the first stage in the electric transmission of energy. When the cells are fully charged, the cables are detached, and the car is ready to start, and during its journey the second stage of the transmission, viz., that of the energy in the cells into the motor, takes place. By the employment of secondary batteries, we have thus carried the operation beyond the limits of the cables. If the charging station is so situated that cars can enter it, the process of charging can be accelerated by making each set of cells detachable from the car, and charging them whilst the car, furnished with a duplicate set, is on the line. As each car comes in, its set of exhausted cells is replaced by a set newly charged, and can go out again within a few minutes. In this case the actual transmission of energy between the dynamo and the cells, which are placed in close proximity, is only over the space of a few yards; yet this energy may, later on, be utilized over a very long line.

A similar system is in use for the propulsion of small boats by electricity. It can be most conveniently applied in the case of launches belonging to vessels which are fitted with the electric light; for the same dynamo which works the incandescent lamps at night can be used to charge, or keep charged, the accumulators in the launch during the day time, so that the latter may at a moment's notice be lowered into the sea, provided with a sufficient store of energy for some hours' run. When the launch is stowed away on deck, its accumulators can also be used for lighting the vessel, if a mishap occurs to the dynamo, or if it be necessary to stop the machinery for some other reason.

Examples of this kind might be multiplied to any extent, but sufficient has been said to show that in the present state of electrical industry, the electrical transmission of energy is a question of great practical interest. Its application is not only confined to the transmission of power, pure and simple, between two distant points, as commonly understood, but it enters more or less into every application of electricity."

Besides the general exposition of the principles involved in the general solution of the great problem, some space is given to classification of existing motors and their work.

## MISCELLANEOUS.

A New Electrotyping Solution.—Dr. Gore, F. R. S., the well known authority on electro-deposition, has discovered that an aqueous solution of asparagine is a good medium for electrolytic baths. The solution he used was not quite saturated, and consisted of about .88 gramme of crystals of asparagine dissolved in 18 cubic centimeters of distilled water. It was feebly acid to the test paper, and was employed at a temperature of about 70 deg. Cent. Some of the liquid was more or less saturated with different metallic oxides, and the resulting baths electrolyzed by currents from one to six cells of zinc and platinum in dilute sulphuric acid. Good deposits of cadmium were thus obtained, .23 gramme of hydrate oxide of cadmium dissolved in 20 cubic centimeters of the solution, using an anode of cadmium and a cathode of copper. Zinc was deposited from .28 gramme of zinc oxide in 23 cubic centimeters of solution. Magnesium in a film was also deposited from calcined magnesia with magnesium and copper electrodes; copper was obtained from cupric oxide with copper and platinum electrodes; mercury from red mercurious oxide with platinum electrodes; and silver from oxide of silver with a silver anode and platinum cathode. In the latter case the deposit was good, the bath consisting of .33 gramme of silver oxide in 20 cubic centimeters of asparagine solution.

Magnesia in Portland Cement.—For a long time magnesia has been supposed to have a bad influence when present in cements, and M. Lechartier has been investigating the nature and cause of its action in structures built with cement, such as basins, dams, and retaining walls, either exposed to air or water. These structures were built by competent engineers in different localities. The cements used did not contain sulphate of lime in a harmful proportion, they had a proper density, and were made of good sands. Nevertheless in all cases the effects were the same, and a slow destruction of the cement went on with time. The explanation of the facts arrived at by M. Lechartier is that the cements employed were really mixtures of Portland cement with magnesia which behaved at first as an inert substance; but little by little the magnesia became hydrated, producing expansion of the mortar and the deterioration of the works. St. Clair Deville has shown that pure magnesia without admixture of silica and alumina can combine with water to form a hydrate of great hardness, but the formation is accompanied with increase of volume. Portland cement alone contains but a small proportion of magnesia. M. Lechartier further observes that the increase of volume of the mortars takes place more rapidly when the water gains access more readily to the mass. Hence the basins of fountains, reservoir walls, and so on, are affected in a comparatively short time.

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## RANKINE'S THERMODYNAMICS.

By DE VOLSON WOOD, M.A., C. E.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

### III.

COMMUNICATIONS received since the publication of my lecture in the last May and June numbers of this Magazine, offer a reason for making the following additions. It would add to the interest of the discussion if other writers would present their views or make criticisms upon what has been said in a public manner; but, as I stated at the outset, that I was not self-satisfied with that work, I the more readily comment upon the subject matter suggested by private communications, as they may be of service to others who are studying the subject. One asks "how does $\frac{Q}{dQ}=\frac{\tau}{d\tau}$? Rankine seems to make

$$\frac{M}{\delta M}=\frac{Q}{\delta Q}=\frac{\tau}{\delta\tau}.$$

Are all the $\delta\tau$'s equal for equal quantities of heat absorbed?" The latter part of this question seems to imply a misconception of Rankine's definition of Q and $\tau$. Neither measures the heat *absorbed*. They refer only to *sensible* heat, or *actual* heat. A substance while absorbing heat m y not only do external work, but also internal work, and all the heat thus absorbed that does *work* is no more heat, and the remainder of the heat absorbed remains as heat—it is sensible heat, and is represented by Q, and, being proportioned to the temperature, is, for a given mass of a substance, also represented by $\tau$, the absolute temperature. All the $d\tau$'s are not equal for equal quantities of heat *absorbed*, but all the $d\tau$'s are equal for equal increments of *sensible* heat, thus, if 10 units of heat be absorbed by a pound of a substance, and 5 units be consumed in changing the molecular constitution—as, for instance, changing the state of aggregation, similar to that of changing ice to water, or water to steam, then only 5 units remain as heat, and Q would not be 10 but 5. Again, if a homogeneous substance whose mass is M containing the quantity Q of sensible heat, be divided into an indefinite number of parts, each being $\delta$M, the quantity of heat will be divided in like manner, and hence each portion, $\delta$M, will contain a quantity $\delta$Q of the heat.

$$\therefore\frac{Q}{M}=\frac{\delta Q}{\delta M}$$

The temperature will not be divided in the same manner, for each $\delta$Q will be of the same temperature as Q, the temperature simply measuring the *intensity* of the heat and not the quantity. But if we conceive the sensible heat, $\delta$Q, of one of the small masses to be composed of an indefinite number of small parts, and each of these to be measured by an increment of temperature, $\delta\tau$, so

that the entire temperature of $\delta Q$ will be $\tau$, then, since the temperature of each $\delta Q$ will be $\tau$ the temperature of Q will also be $\tau$. This idea may be illustrated by means of rectangles; thus let EFGH, Fig. 25, represent the mass M of the sub-

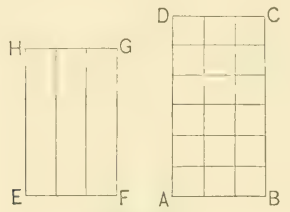


Fig. 25

stance, and ABCD the quantity of heat Q. Then if these rectangles be divided into the same number of equal vertical strips, one of the strips in EG may be represented by $\delta M$, and in AC by $\delta Q$; and we at once have

$$\frac{Q}{M}=\frac{\delta Q}{\delta M}.$$

Let a scale of temperatures from absolute zero be represented by the line AD, and let this be divided into equal parts, then will horizontal lines through these points divide AC or Q into the same number of equal parts, each of which will be $\delta'Q$. If $\tau$ be the temperature, one of the divisions of $\tau$ will be $\delta\tau$, so that we have

$$\frac{Q}{\tau}=\frac{\delta' Q}{\delta\tau}$$

If, however, the *number* of divisions of AC into horizontal strips be the same as those of the vertical strips, then will $\delta'Q=\delta Q$, and hence

$$\frac{Q}{\tau}=\frac{\delta Q}{\delta\tau},$$

and this is always possible, for we may begin with $\tau$, making $\tau\div\delta\tau=n=$the number of divisions, and then divide Q the other way making $\delta Q=Q\div n$, and $\delta M=M\div n$; thus we have:

$$\frac{M}{\delta M}=\frac{Q}{\delta Q}=\frac{\tau}{\delta\tau}=n.$$

To illustrate further. In Fig. 26, in passing from the state A to the state B, the heat *absorbed* has been shown to be represented in foot-pounds by the indefinitely extended area MABN. This is not the Q above used. Q may be the *sensible* heat in the body in the state A, capable of doing the external work $MAv_1x$, and the internal work $maAM$ by an indefinite expansion without transmis-

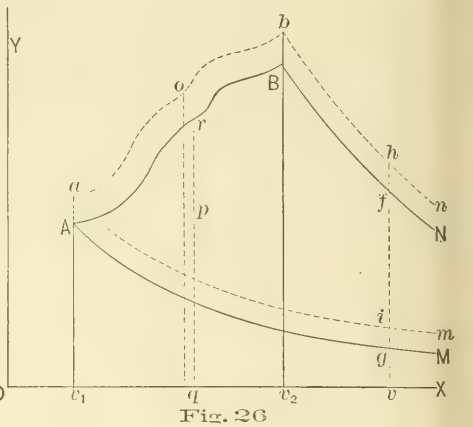


Fig. 26

sion of heat. In the discussion of this case on pages 424 and 425, a term was dropped, and thus the reasoning was apparently vitiated; and we here restate the case as it should have been. In Fig. 26 we have *nbam* equal to the heat absorbed in doing both external and internal work in passing from the state A to the state B; and if $H_a$ be the sensible heat at state A, and $H_b$ that at state B; then

$$nbv_2X+bv_2v_1a-mav_1X=nbam$$

or $$H_b+bv_2v_1a-H_a=nbam$$
$$=nbBN+NBv_2X+baAB$$
$$+Bv_2v_1A-maAM-MAv_1X$$
$$=MABN,$$

since

$$nbBN+baAB-maAM=0,$$

or $$S_b+S-S_a=0. \qquad (p_1v)$$

But the heat in the body in foot-pounds in the state B *plus* the work, both external and internal, done in passing from the state A to state B, *minus* the heat, in foot-pounds, in the state A must be the heat absorbed; hence MABN is the heat absorbed in passing from A to B. But

$$bv_2v_1a=v_1ABv_2+baAB$$
$$=\int pdv+S$$

$$= \int p dv + S_a - S_b ;$$

$$\therefore \text{MABN} - \int p dv = H_b - H_a - S_b + S_a$$

which should be substituted for equation ($n$), page 425.

How does it appear that the *expression* of the Second Law includes both external and internal work, as Rankine claims; and how does it appear that the total work may be deduced from that of the external? In attempting to explain these more fully, we can scarcely do better than amplify what Rankine has done, although we will give different methods.

In Fig. 27 let the substance whose initial volume is $Ov_1$ at the pressure $v_1$A and temperature $\tau$, expand isothermally at the temperature $\tau$ to the volume $Ov_2$ and pressure $v_2$B; external work will be done, represented by $v_1$ $v_2$ BA, and internal work represented by AB$ba$ let AM and BN be adiabatics proper to the substance through A and B respectively, then, as has been shown, will this indefinitely extended area MABN represent the total heat absorbed in passing from the state A to state B, and since the temperature has been maintained constant by a supply of heat from an external source, the intrinsic energy of the substance remains constant, and hence will be the same at the state B as at A, and hence all the heat absorbed has been transmuted into work of some kind, whether it be external or partly external and partly internal. Hence, the area MABN in terms of heat units expressed in foot-pounds must give the entire work which the heat absorbed

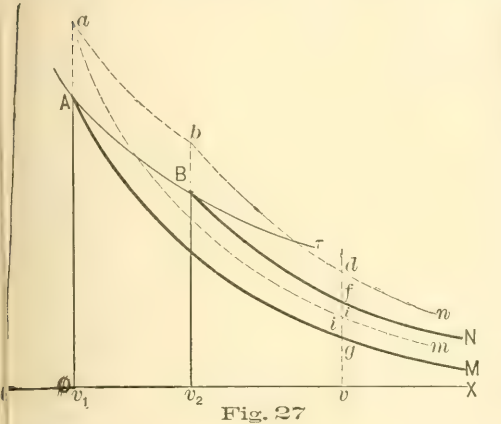


Fig. 27

at constant temperature does. We therefore seek an expression for this area.

In Fig. 28 conceive isothermals $fh$, $ji$, etc., drawn across the area between the adiabatics AM and BN, representing succesive equal decrements of temperature, then will the successive strips thus formed be equal. For, after the substance has expanded from A to B isothermally, let it expand without transmission of heat along the adiabatic BN, the process being arrested when the temperature $\tau$ has fallen an amount $\triangle \tau$, at which the pressure may be represented by the ordinate of $h$ above OX; then compressing the substance isothermally to $f$ and adiabatically to A. In this process heat represented by MABN has been absorbed, and M$fh$N rejected, and since the substance has been worked in a complete cycle, the resultant work is all external, the resultant internal work being zero. Beginning again at A, passing to B, thence adiabatically until the temperature has fallen $2 \triangle \tau$ at which the pressure will be the ordinate of $i$, thence isothermally to $j$, thence adiabatically to A. The same heat MABN has been absorbed in this as in the former case, but only M$ji$N has been rejected, and twice as much has been transmuted into external work as before. But twice the heat when worked in such a cycle with any substance will do twice the external work, at least within the limits of the errors of observation. We will give a mere outline of the reason. Sir William Thomson proposed an "absolute thermometric scale" in which equal quantities of work done

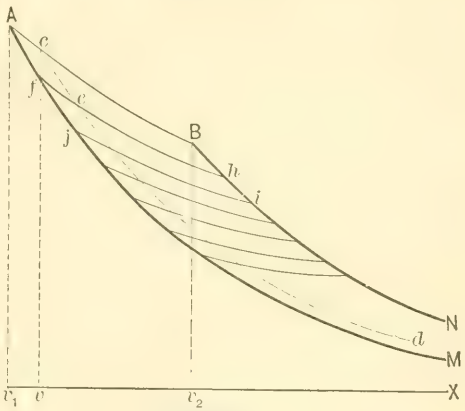


Fig. 28

Sensible Heat

by heat as the agent in a reversible engine should correspond to equal divisions on a scale, and that the scale thus formed should be considered a scale of temperatures; *but it was afterwards found that the equal divisions of an air thermometer, within the range used in practice, agree with the "absolute scale" within the limits of the errors of observation, so that the latter is substituted for the former, and by reversing the statement of Thomson, we may now say that a given mass of any substance worked according to Carnot's cycle through the same range of temperature as measured by an air thermometer on any part of its scale, will produce the same amount of *external* work. For practical purposes the mercurial thermometer may be considered as coinciding with the air thermometer,† so that, when we are expressing a general idea, without attempting to express the refinements of the science, we may say that when work is done by heat according to Carnot's cycle the differences between the highest and lowest temperatures through which the substance is worked, measured according to a standard mercurial thermometer, are proportional to the respective works done, or

$$t' - t'' : t_1 - t_2 :: w' : w_1$$

or in our own case

$$\triangle\tau : 2\triangle\tau :: w : 2w.$$

or generally

$$\triangle\tau : m.\triangle\tau :: w : m.w.$$

If now the divisions, $\triangle\tau$, which we have assumed are commensurable with $\tau$, the temperature of AB, we would find the area of MABN by multiplying the area of AB$hf$ by the number of divisions. The question of commensurability will be removed by making $\triangle\tau$ indefinitely small, and equal to $d\tau$, in which case the number of divisions will be $\frac{\tau}{d\tau}$. To find the area of AB$hf$, we first find the area of A$cef$A, where $ce$ is an adiabatic through $c$ and $c$ is indefinitely near A, so that the horizontal distance between A and $c$ will be $dv = v_1 v$.

Representing the area A$cef$ on an enlarged scale, as in Fig. 29, prolong $ef$ to $v_1$A at $x$, then will A$x$ represent the fall in pressure at the volume $v_1$ due to a fall of temperature $d\tau$, hence the *rate of change* of the pressure will be $\frac{dp}{d\tau}$ and for a change of temperature $d\tau$ we have

$$\mathrm{A}x = \frac{dp}{d\tau} d\tau.$$

The area of A$cef$ will *ultimately* equal the rectangle A$czx$, for they are between the same parallels A$c$ and $xe$; but the area of A$czx$ will be A$x$ multiplied by the perpendicular between A$x$ and $cz$ or $dv$; hence

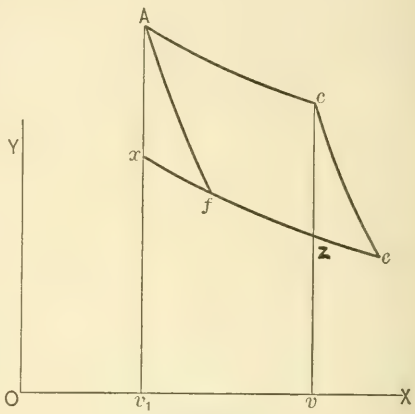


Fig. 29

$$Area\ \mathrm{A}czx = \frac{dp}{d\tau} d\tau dv$$

since each of the elementary areas between $AM$ and $cd$ Fig. 28, formed in the manner above described, are equal to each other, the number being $\frac{\tau}{d\tau}$, we have

$$\text{Area MA}cd = \frac{\tau}{d\tau}.\frac{dp}{d\tau} d\tau dv = \tau.\frac{dp}{d\tau} dv \qquad (qz)$$

which was sought.

The area MABN may be considered as the sum of an indefinite number of strips, A$h$, $fi$, etc., in which case the total area will be the area of AB$hf \times \frac{\tau}{d\tau}$, or

$$\frac{\tau}{d\tau} \int \frac{dp}{d\tau} d\tau dv = \tau \int \frac{dp}{d\tau} dv,$$

or the sum of areas like MA$cd$, in which case the area will be the integral of equation $(qz)$ in reference to $v$ between the limits $v_2$ and $v_1$; or

* Math and Phys Papers, Vol. I., pp. 393-395.
† Rankin's "Steam Engine," p. 234.

Area MABN=

$$\int \tau \frac{dp}{d\tau} dv = \tau \int_{v_1}^{v_2} \left\{ \left(\frac{dp}{d\tau}\right)_{v \text{ const.}} \right\}_{\tau \text{ const.}} dv \quad (rz)$$

which, as already stated, must be the total work done. The value of $\left(\frac{dp}{d\tau}\right)_v$ is to be obtained from the equation of the gas. Thus for a perfect gas, we have

$$\frac{pv}{p_0 v_0} = \frac{\tau}{\tau_0}, \text{ or } pv = \mathrm{R}\tau;$$

$$\therefore \left(\frac{dp}{d\tau}\right)_v = \frac{\mathrm{R}}{v} = \frac{p}{\tau}.$$

For imperfect gases we have in some cases, like carbonic acid gas,

$$pv = \mathrm{R}\tau - \frac{a}{\tau v};$$

$$\therefore \left(\frac{dp}{d\tau}\right)_v = \frac{\mathrm{R}}{v} + \frac{a}{\tau^2 v^2} \quad (r_1 z)$$

$$= p + \frac{2a}{\tau^2 v^2}$$

for which case the area MA$cd$ will be

$$\tau \frac{dp}{d\tau} = \left(\mathrm{R}\frac{\tau}{v} + \frac{a}{\tau^2 v^2}\right) dv$$

which may readily be integrated for $\tau$ constant, giving the area MABN for this case.

An element of the external work $v_1 v_2$ BA, Fig. 27, will be

$$du = p dv,$$

in which $v$ being an independent variable does not admit of a second differential, and differentiating regarding $p$ as a function of $\tau$, we have

$$\frac{d(du)}{d\tau} = \frac{dp}{d\tau} dv$$

$$\therefore \tau \frac{d(du)}{d\tau} = \tau \frac{dp}{d\tau} dv \quad (sz)$$

the second member of which is the same as the last member of equation ($qz$).

The integral of equation ($sz$) is

$$\tau \frac{d\mathrm{U}}{d\tau} = \tau \int \frac{dp}{d\tau} dv = \mathrm{W} \quad (tz)$$

the second member of which is the same as equation ($rz$), and the first member is $\tau$-times the rate of doing work per unit of absolute temperature; hence the total work, W, both external and internal, during an isothermal expansion, is $\tau$ times the rate of doing external work per unit of temperature.

In the last expression,

$$d\mathrm{U} = d \int_{v_1}^{v_2} p dv.$$

The integral of the differential of a quantity differs from the quantity by a constant; thus

$$\int d(x^3) = \int 3x^2 dx = x^3 + c.$$

But the differential of the integral of a quantity is the quantity itself; thus

$$d \int (3x^2 dx) = d(x^3 + c) = 3x^2 dx.$$

Rankine's method, pp. 308, 309, of "Steam Engine" of establishing equation ($rz$) is substantially as follows:—

$$\frac{\text{Area ABhf}}{\text{Area MABN}} = \frac{d\tau}{\tau}, \text{ also } = \frac{\int \frac{dp}{d\tau} dv\, d\tau}{\text{Area MABN}};$$

$$\therefore \text{Area MABN} = \tau \int \frac{dp}{d\tau} dv$$

Thomson's first solution consisted in first proving that the ratio of the limiting area A$cef$, Fig. 28, to that of the whole heat supplied was constant for all substances at the same temperature. Thus if M be the rate of supplying heat per unit of volume in order to maintain a constant temperature, then

$$\frac{\frac{dp}{d\tau} d\tau dv}{\mathrm{M} dv} = \text{constant for } \tau \text{ constant},$$

then if $\mu$ be a function of the temperature only, we have

$$\frac{dp}{d\tau} dv = \mu \mathrm{M} dv$$

Thomson has given to $\mu$ the title "Carnot's Function" (Math. and Phys. Papers Vol. I., pp. 187, 188, and pp. 129-134). Thomson remarks that $\mu$ "may vary with the temperature in a manner that can only be determined by experiment" (*ibd.* p. 187), but after finding that

$$\mu = \frac{\mathrm{J}}{\frac{1}{\mathrm{E}} + t} = \frac{\mathrm{J}}{\tau} \text{ approximately},$$

*ibd.* p. 389, a form suggested by Joule in 1828, *ibd.* p. 199, where $\tau$ is the temperature above absolute zero, resulting from

extending any one of the ordinary scales whose fixed points are the temperature of melting ice and of boiling water, downward a distance below the point of melting ice equal to the reciprocal of the coefficient of expansion of atmospheric air, he proposed an absolute scale according to which the above equality should be exact, defining temperature as the reciprocal of Carnot's function (*ibd.* p. 393). Thomson's and Joule's experiments showed that the air thermometer differed so slightly from that of an ideally perfect gas, that it may be substituted for the latter, and $\frac{J}{\tau}$ for such a thermometer becomes practically accurate; hence substituting this value of $\mu$ above gives

$$JM.dv = \tau \frac{dp}{d\tau} dv.$$

Thomson's method is followed, substantially, by Tait in his Sketch of the History of Thermodynamics, and by Stewart in his work on Heat.

Next, consider the case in which more heat is absorbed during expansion than is necessary for maintaining a constant temperature, so that while expanding from $v_1$ to $v_2$, Fig. 30, the external pressures will be limited by the curve AceB. From the state A let the expansion be isothermal from A to *b*, then will the heat absorbed be represented by the area between A*b* and the adiabatics AM and and $bm_1$, as just shown, and the total work done will be

$$\tau \int_{v_1} \frac{dp}{d\tau} dv$$

At *b* let the volume be maintained constant, while the pressure is increased from *v'b* to *v'c*, an amount equal *bc*, by the absorption of heat. Since no external work is done during this operation, the energy represented by the area $m_1bcm_2$, between the adiabatics and *bc*,

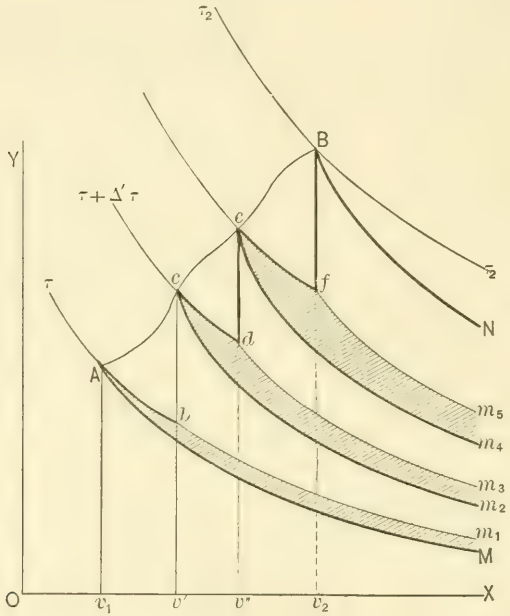



Fig. 30

will exist in the substance in the form of heat energy, and if no internal work be done this area will represent the heat absorbed. No internal work will be done if the specific heat of the substance be uniform between the limits of the temperature at *b* and *c*, as in the case of perfect gases; for which the increase of pressure *bc* will be proportional to the increase of temperature. Thus, if we have

$$pv = R\tau,$$

then

$$dp = Cd\tau, \qquad (uz)$$

when *v* is constant, and C equal to R÷*v*.

According to the dynamic theory of heat, the essential energy in the body—or that which makes it hot after abstracting all work—varies directly as the absolute temperature, and for which the specific heat for a constant state of aggregation for a particular body is constant. Let $k$ be this specific heat, called by Rankine "the *real* dynamic specific heat," then for an increase of temperature $\Delta'\tau$, the stored actual energy will be

$$k.\Delta'\tau = m_1 bcm_2. \qquad (vz)$$

If the gas be not perfect, the pressure will not increase directly as the temperature, and the departure from the gaseous law will be due to internal work for an increase of temperature at constant volume; for which case the area $m_1 bcm_2$ will not represent the heat *absorbed* in raising the pressure from $b$ to $c$, and, generally more heat will be absorbed than thus represented, but, at the same time this area will represent the entire *external* work which the substance can do by an indefinite expansion on account of the heat imparted from state $b$ to state $c$. There appears to be no space within the figure NBAM for representing the *internal* work due to changes of temperature only, for it is already covered by figures representing work done and intrinsic energy imparted to the substance; but since the internal work is at the expense of heat absorbed, it may be represented by a strip somewhat similar to those shown in the figure. If it could be known how far the substance must be expanded beyond $b$ at the constant temperature $\tau$ in order that the area between adiabatics would equal the internal work done in raising the temperature from that at the state $b$ to that at the state $c$, the value of such work would be the integral of $\tau\frac{dp}{d\tau}dv$ between the proper limits for $v$. But we are unable thus to find it, and equally unable to determine a height on the prolongation of $bc$ such that the area between two adiabatics drawn through the extremities of such a line will equal the required amount of heat so lost. Rankine's method is equivalent to considering the required value as an area, one side of which, at least, is bounded by an isothermal indefinitely extended. Thus, since $\tau\frac{dp}{d\tau}$ may be considered as equivalent to an ordinate eq. $(rz)$, so its differential, or $\tau\frac{d^2p}{d\tau^2}d\tau$ may be considered as the increase of this ordinate due to an elementary change of temperature in the equation of the gas, and $= pq$, Fig. 31. Then will the entire area $c\mathrm{CD}d$ for a change $d\tau$ be

$$\left\{\tau\int_{\infty}^{v_1}\left(\frac{d^2p}{d\tau^2}\right)_v dv\right\}d\tau \qquad (wz)$$

It is plain from this treatment that equation $(wz)$ will not give the loss of heat due to internal work at constant volume for finite changes of temperature, since for such a case $\tau$ is variable while in $(wz)$ $\tau$ in the brackets is constant, but as it is known to be small compared with the value of $k$ it is assumed to be constant and in all ordinary cases entirely neglected.

It may be better to consider the area $c\mathrm{CD}d$, Fig. 31, as representing the heat destroyed by internal work for a change of one degree of temperature, on the supposition that the change is uniform for that degree, in which case its value will be expressed by the quantity within the $\{\ \}$ in expression $(wz)$, and that quantity will be the rate of change per degree of temperature, and then for the change $d\tau$ the amount of heat destroyed by internal work at constant volume will be the value of the entire expression of $(wz)$ as before.

This mode of treatment by the author is not satisfactory to the writer. It is true that the heat destroyed by internal work may be represented by an area, but its true value is not represented by an area bounded by an isothermal. If the heat destroyed would have raised the pressure an amount equal to $c\mathrm{D}$, Fig. 31, if the

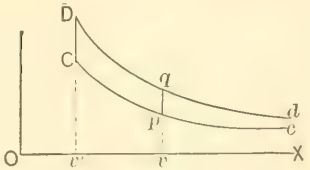


Fig. 31

substance had the same specific heat at that state and were a perfect gas, then would the area representing this heat be that between two adiabitacs through C

and D, like the area $m_1bcm_2$, Fig. 30. In order to expand the substance along an isothermal $c$C, heat must be supplied continually, so that if the analysis by which expression ($wz$) was established were correct, it would seem that the expression would give a value in excess of the heat destroyed; and if this were so it could the more safely be neglected in the equation for heat absorbed, since its value is small according to the author's analysis. We are not in doubt as to the author's intended treatment of the integral of this expression, since he has made a numerical reduction of expression ($wz$) for carbonic acid gas (*Trans. of the Royal Society of Edinburgh, Vol. XX.*), from which it appears that this expression is treated in a manner quite similiar to that of the fundamental one, $\tau\frac{dp}{d\tau}dv$; that is, $\tau$ is heated as constant, $\frac{dp}{d\tau}$ is differentiated regarding $v$ as constant, giving $\frac{d^2p}{d\tau^2}d\tau$, and $\frac{d^2p}{d\tau^2}dv$ is integrated as if $\tau$ in the value of $\frac{d^2p}{d\tau^2}$ were constant. Using the equation for carbonic gas, we find by differentiating equation ($r_1z$), considering $v$ as constant, as we should,

$$\frac{d^2p}{d\tau^2}=-\frac{2a}{\tau^3v^2};$$

$$\therefore\ \tau\frac{d^2p}{d\tau^2}=-\frac{2a}{\tau^2v^2}$$

which, according to our understanding of Rankine, is the ordinate $qp$, Fig. 31, and, being negative, may be considered as operating against an increase of the pressure as it really does. Considering $\tau$ as constant, and multiplying by $dv$, we have for the integral of the expression

$$-\frac{2a}{\tau^2}\int_{\infty}^{u}\frac{dv}{v^2}=\frac{2a}{\tau^2v}$$

as already given in equation ($gz$), page 480. A numerical reduction of this quantity, for particular values of $\tau$ and $v$ is given on page 480 of the last June number of this Journal, and is precisely similar in form to that given by Rankine in the *Transactions* above refered to; and the value thus found is treated as constant during the integration in reference to $d\tau$ in expression ($wz$). Thus far the treatment is precisely similiar to that of the expression $\tau\int_v^v\frac{dp}{d\tau}dv$ except that in the last expression the limits of integration are finite, while in the former, one of the limits is infinite. This exception is, at least, suggestive. The area considered is not a narrow strip just above $Ab$, Fig. 30, limited by the ordinates $v_1$A and $v'b$, and it should not be, for such a strip would be due to an increase of the *observed* value of $\tau$, making it $\tau+d\tau$, and the area of such a strip would be

$$(\tau+d\tau)\int_{v_1}^{v'}\frac{dp}{d\tau}dv-\tau\int_{v_1}^{v'}\frac{dp}{d\tau}dv$$

$$=d\tau\int\frac{dp}{d\tau}dv=\int\frac{dp}{d\tau}\,dv\,d\tau,$$

as originally found.

Then, too, this work is not done during the expansion from $v_1$ to $v'$ but at the fixed volume $v'$. The area considered by the author is one of indefinite extent, as indicated by the limits.

We analyze this term as follows: In Fig. 27, at the volume $v_2$ and temperature $\tau$ the external pressure is $v_2\mathrm{B}=p$, and the virtual pressure resulting from internal work during the isothermal expansion is

$$v_2\mathrm{B}=\tau\frac{dp}{d\tau},$$

when $\frac{dp}{d\tau}$ may be obtained by an experiment upon the gas, or found from its equation, and $\tau$ is simply the observed absolute temperature; hence

$$\mathrm{B}b=\tau\frac{dp}{d\tau}-p,$$

is a virtual pressure doing internal work under an isothermal expansion. If now there be a change of temperature, $p$ as well as $\tau$ will change, and $\frac{dp}{d\tau}$ necessarily change, and for an infinitesimal change of temperature, the virtual increase in the ordinate representing internal work will be the differential of B$b$, or

$$d\tau\frac{dp}{d\tau}+\tau\frac{d^2p}{d\tau^2}d\tau-\frac{dp}{d\tau}d\tau=\tau\frac{d^2p}{d\tau^2}d\tau$$

which is of the same form as before obtained, but in this case $\tau$ has been considered variable, while in the former case it was considered constant. This differ-

ence is of little or no importance in considering the state B, but is vital in what follows. As before stated, we do not yet know how much heat must be absorbed, under the conditions imposed, in order to produce an increase of the ordinate equal to $\tau\frac{d^2p}{d\tau^2}$ at B; but considering that the adiabatic BN is a function of $p$ and $v$ only, and hence is a fixed line for any given substance, we may conceive that another line is drawn near it, passing through a point at a distance $\tau\frac{d^2p}{d\tau^2}$ above B; then will the imaginary strip between these two lines be the required area. (Or, if preferred, conceive that the strip is just above *bn*.) Let $p_2$, $v$, be the co-ordinates of any point in the adiabatic BN, then will the vertical distance between BN and the imaginary line above described, be

$$\tau\left(\frac{d^2p_2}{d\tau^2}\right),$$

where $\tau$ is the temperature at the point considered; and the area of the entire imaginary strip will be

$$\int_{v_2}^{\infty}\tau\frac{d^2p}{d\tau^2}dv,$$

in which the order of the limits will be reversed if the above gives a negative value. Or, the order of the limits may be changed and a minus sign placed before the expression. Another way of considering the order of the signs and limits is given on page 482.

It appears from the last expression that the co-efficient of $v$ will depend upon $\tau$, unless $\tau\frac{d^2p}{d\tau^2}$ is independent of $\tau$, which is not the case with any known gas except for sensibly perfect gases when that term reduces to zero; and since $\tau$ cannot, generally, be expressed as a function of $v$ the expression cannot be integrated with $\tau$ a variable. But knowing from experiment that the specific heat of the more perfect gases, such as air and carbonic acid, are nearly uniform—and these are the only ones especially considered by the author in discussing this term, page 317 of his text—the term $\tau\frac{d^2p}{d\tau^2}$ will be small in all practical cases, and hence the imaginary area, above considered, will depend for its value chiefly upon the function of $v$, so, as an *approximation*, we consider $\tau$ constant; after which we may proceed as our author has done. In this way we find the approximate value of expression (*wz*) for a finite change of temperature. The value of the change of the specific heat at constant volume due to changes in the temperature is determined by direct experiment, rather than by the above analysis in which the fundamental equations are themselves more or less empirical. Still $\frac{d^2p}{d\tau^2}$ and $\frac{d^2v}{d\tau^2}$ represent the deviation of the laws of actual gases and other fluids from the ideal condition of a perfect gas, at least qualitatively if not strictly quantitatively.

At *c*, Fig. 30, let work be done by expansion at constant temperature to *d*, thence at constant volume heat absorbed raising the pressure an amount *de*, and temperature an amount $\Delta''\tau$; thence to *f* and finally to B, where the temperature is $\tau_2$. The shaded part represents heat absorbed and work done at constant temperature, and the unshaded strips the heat absorbed which remains in the substance as heat, and which is capable of doing external work, while the heat absorbed doing internal work at constant volume under a change of temperature is not shown in the figure. It thus appears that the entire heat absorbed by a substance may be considered in two parts: —1st, *as doing work entirely by isothermal expansion*, and, 2d, *as producing a change of energy*.

Adding the several quantities, we have for the total heat *absorbed* during the expansion from $v_1$ to $v_2$ and of pressure from $v_1$A to $v_2$B,

$$\mathrm{H}=_{a,b}\left\{\begin{array}{l} k.\Delta'\tau+k.\Delta''\tau+\quad .\quad .\quad . \\ +\tau+\int_{v_1}^{\infty}\frac{d^2p}{d\tau^2}dv.\Delta'\tau+ \\ (\tau+\Delta'\tau)\int_{\infty}^{v'}\frac{d^2p}{d\tau^2}dv.\Delta''\tau+ \\ \quad .\quad .\quad .\quad .\quad .\quad .\quad . \\ +\tau\int_{v_1}^{v'}\frac{dp}{d\tau}dv+ \\ \quad (\tau+\Delta'\tau)\int_{v'}^{v''}\frac{dp}{d\tau}dv+, \text{ \&c.} \end{array}\right\} (xz)$$

Conceive the number of sides of the inscribed polygon A*bcdef* . . . increased in-

definitely, the vertices falling on the line A*ce*B, then

$$k.\triangle'\tau + k.\triangle''\tau + \&c. = \int k d\tau = k(\tau_2 - \tau_1)$$

and, considering the coefficients of $\triangle'\tau$, $\triangle''\tau$,&c., in the second and third line as equal to each other, and equal to P,

$$\Sigma\left\{\left(\tau + \triangle\tau\right)\int \frac{d^2p}{d\tau^2} dv.d\tau\right\} =$$

$$\int_{\tau_1}^{\tau_2} \mathrm{P} d\tau = \mathrm{P}\left(\tau_2 - \tau_1\right),$$

and the sum of the quantities in the third line is the total work, both external and internal, done at the successive differential isothermal expansions. The external work being represented by $\int p dv$, and the internal by S′, equation (*xz*) becomes

$$\underset{a,b}{\mathrm{H}} = \left(k + \mathrm{P}\right)\left(\tau_2 - \tau_1\right) + \int_{v_1}^{v_2} p dv + \mathrm{S}' \quad (yz)$$

Letting S be the entire internal work done due both to change of temperature and to isothermal expansion, equation ($p_1 z$), then

$$\mathrm{S} = \mathrm{S}' + \mathrm{P}\left(\tau_2 - \tau_1\right) = \mathrm{S}_a - \mathrm{S}_b$$

and the preceding equation becomes

$$\underset{a,b}{\mathrm{H}} = k\left(\tau_2 - \tau_1\right) + \int_{v_1}^{v_2} p dv - \mathrm{S}_b + \mathrm{S}_a$$

which is Rankine's equation (2), page 313.

Several cases arise under this equation, of which we consider the following:

*a.* Let work be done under an isothermal expansion, and heat supplied at constant volume.

This is the case just considered and is shown in Fig. 30.

*b.* Let work be done under an isothermal expansion and heat abstracted at constant volume.

In this case the final temperature will be less than the initial, or $\tau_2$ be less than $\tau_1$, and the first term of equation (*yz*) will be negative.

This case is shown in Fig. 32, when MA$bm_1$, $m_2cdm_3$ represent heat *supplied* during isothermal expansion and $m_1bcm_2$, $m_3d\mathrm{B}m_4$, heat *abstracted* at constant volume.

*c.* Let work be done under an isothermal compression and heat abstracted at constant volume.

In this case heat must be abstracted during the compression, and the case will be illustrated by Fig. 30, if the substance

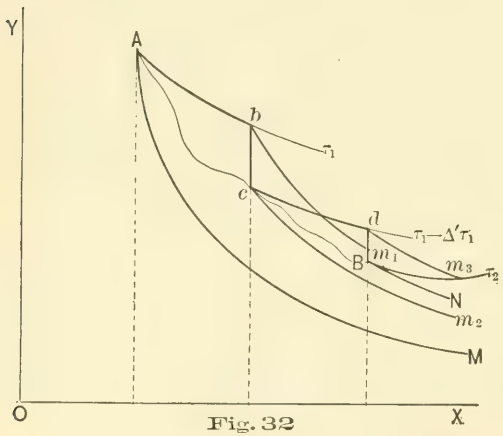



Fig. 32

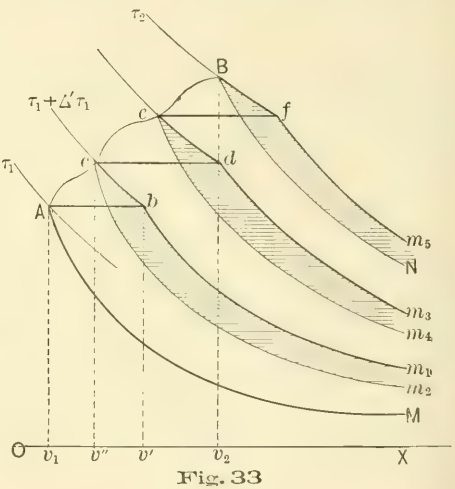



Fig. 33

be worked from the state B to that of the state A. Work is here done upon the substance throughout the entire operation.

*d.* Let work be done under an isothermal compression and heat supplied at constant volume.

This case is illustrated by Fig. 32, where the substance is worked from the state B to that of A, and $\tau_2$ considered as the initial and $\tau_1$ as the final temperatures. Here work is done on the substance isothermally, and hence heat is abstracted during this operation; but energy is im-

parted to the substance by the absorption of heat at constant volume.

This graphical solution may be applied directly to Article 148 of the author, in which $\tau$ rnd $p$ are made the independent variables, instead of $\tau$ and $v$ as in the preceding solution. In Fig. 33, let $Ov_1$ be the volume of a pound of the substance, $AB$, the locus of the pressures and volumes as before, and which for brevity is called the "path of the fluid." At $A$ let expansion be made at constant pressure, then will the path of the fluid be a horizontal line A$b$, and the heat supplied will be represented by the area MA$bm_1$ indefinitely extended, AM and $bm_1$ being adiabatics. If $k_p$ be the heat

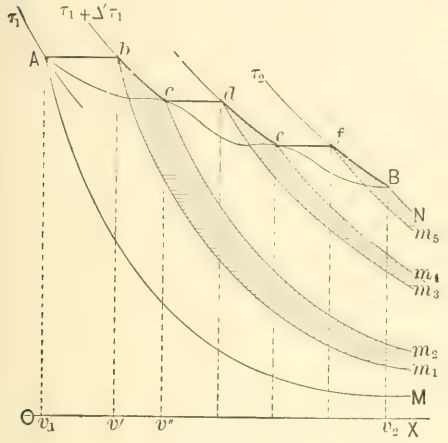



Fig. 34

necessary to increase the temperature of a pound of the substance one degree at constant pressure, and $\Delta'\tau$ the increase of temperature in expanding from $v_1$ to $v'$, then will the heat represented by MA$bm_1$ be

$$\Delta'\tau \,.\, k_p$$

if we neglect, as we will now do, the internal work due to the change of volume at constant pressure. At $b$ let the substance be compressed isothermally until its path $bc$ intersects the path AB at $c$, then will the heat *abstracted* during this operation be represented by $m_1bcm_2$ indefinitely extended and equals

$$\left(\tau+\Delta'\tau\right)\int_{v''}^{v'}\frac{dp}{d\tau}dv$$

as has been shown in the preceding investigation. The heat absorbed, therefore, in passing from A to $c$ along the paths A$b$ and $bc$, will be

$$\Delta'\tau \,.\, k_p - \left(\tau+\Delta'\tau\right)\int_{v''}^{v'}\frac{dp}{d\tau}dv$$

and so on to B.

It is advisable, however, to consider, for the general case, one in which the given conditions operate in the same sense; we therefore pass to the case in which heat is absorbed during both operations as shown in Fig. 34, in which the area MA$bm_1$ represents the heat absorbed at constant pressure, $m_1bcm_2$ heat absorbed at constant temperature, and so on. Hence the total heat absorbed in passing in this way from state A to that of state B will be

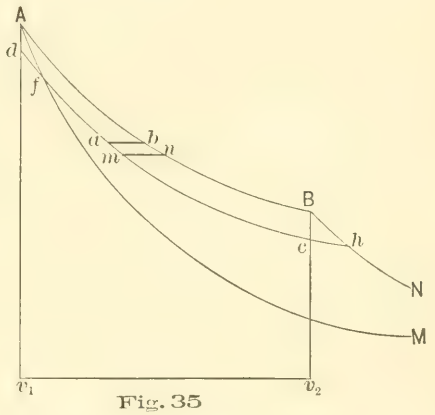



Fig. 35

$$\mathrm{H}=k_p \,.\, \Delta'\tau + k_p \,.\, \Delta''\tau + \&c. \ldots$$
$$+\left(\tau+\Delta'\tau\right)\int\frac{dp}{d\tau}dv + \ldots \tau_2\int\frac{dp}{d\tau}dv$$

and passing to the limit, the heat absorbed when the path of the fluid is A$c$B will be

$$\mathrm{H}=k_p\left(\tau_2-\tau_1\right)+\Sigma_{v_2}^{v_1}\tau\frac{dp}{d\tau}dv \qquad (z_1z)$$

It remains to change the independent variable from $v$ to $p$ in the last term of this equation. Let the area MABN, Fig. 28, which is the same for this case as in the former one, be divided as before by isothermals differing by the constant quantity, $d\tau$, the number of spaces or strips will be $\tau \div d\tau$ as before, and we proceed to find the area of the upper strip AB$hf$. The value of $dv$ in this case is not arbitrary, but is made to depend upon the temperature. To show its value graphically, let AB and $fh$, Fig. 35,

represent two consecutive isothermals, then, since $\frac{dv}{d\tau}$ is to be independent of the pressure, any horizontal line, as $ab$, limited by the isothermals, will be $dv$, and will be written $\frac{dv}{d\tau}d\tau$. The depth of an elementary parallelogram $abcd$ will be arbitrary and equal $dp$; hence

$$\text{area } abcd=\frac{dv}{d\tau}d\tau dp.$$

Ultimately, the area AB$hf$ will equal A$Bcd$, and we have

$$area\ \text{AB}hf=\int_{p_1}^{p_2}\frac{dv}{d\tau}d\tau dp$$

$$=-\int_{p_2}^{p_1}\frac{dv}{d\tau}d\tau dp$$

and the area

$$\text{MABN}=-\frac{\tau}{d\tau}\int_{p_2}^{p_1}\frac{dv}{d\tau}d\tau dp$$

$$=-\tau\int_{p_2}^{p_1}\frac{dv}{d\tau}dp$$

which, substituted in equation $(z_1 z)$, gives

$$\text{H}=k_p\left(\tau_2-\tau_1\right)-\tau\int_{p_2}^{p_1}\frac{dv}{d\tau}dp$$

which is the author's equation (1) of article (248). The author writes zero for the inferior limit of $p$, which value represents an indefinite expansion, but as isothermal expansion is necessarily finite, and as an infinite isothermal expansion demands an infinite amount of heat, doing also an infinite amount of work, both limits should be finite. The author, in his applications, uses finite limits, as on pages 319 (lower part), 322, 323, 349, 387, 397 and other places. The zero limit for $p$ is, unfortunately, used on pages 314, 315, 319, 328, where a finite value is advisable, and in practical cases is absolutely necessary, and the same remark applies to the infinite limit in equation (1), page 319. To show the effect of using these limits, take the case of a perfect gas, when we have:

$$pv=\text{R}\tau,$$

$$\therefore \frac{dp}{d\tau}=\frac{\text{R}}{v},$$

and hence

$$\int_{\infty}^{v}\frac{dp}{d\tau}dv=\text{R}\int_{\infty}^{v}\frac{dv}{v}=\text{R}\left(\log.\ v\right)_{\infty}^{v}$$

$$=\text{R}\ (\log.\ v-\infty)=-\infty$$

and similarly for the expressions $\int_{o}^{p}\frac{dv}{d\tau}dp$ and $\int_{o}^{\tau}\frac{d\tau}{\tau}$. These points are mentioned because they are liable to perplex a student not already familiar with the subject. The infinite limit for $v$ is correctly used on pages 312, 313 and 316, as we have shown in these articles, and the zero limit for $p$ on page 317; but these expressions refer to different areas than the preceding.

The fact that the specific heat at constant pressure exceeds that at constant volume for sensibly perfect gases, may also be illustrated graphically. Thus, in Fig. 36, let $\tau_1\tau_1$ and $\tau_2\tau_2$ be two isother-

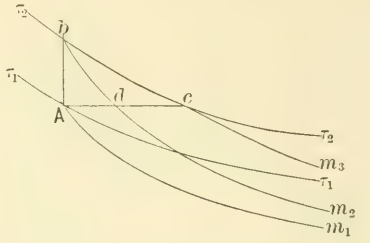



Fig. 36

mals differing by one degree. At any point $a$ of $\tau_1\tau_1$ draw the vertical $ab$ and the horizontal $ac$, and through $a$, $b$ and $c$ draw adiabatics, then will $m_1abm_2$ represent the specific heat at constant volume, and $m_1acm_2$ the specific heat at constant pressure, but since the adiabatics slope downwards more rapidly than the isothermals, the adiabatic $bm_2$ will intersect $ac$ in some point as $d$; hence $m_1acm_2$ exceeds $m_1abm_2$. Since writing the above I find that Rankine has used a figure similar to Fig. 36 for determining the ratio of the apparent specific heats (*Phil. Trans. Roy. Soc.*, 1854).

We here state the two laws of thermodynamics in language as nearly parallel as we are able, that their distinctive characteristics may be the more quickly seen.

First Law.—Mechanical energy and heat energy are mutually convertible, the

transfer being made in any manner, at the rate of J foot-pounds *per British thermal unit* (J being Joule's equivalent).

Second Law.—Mechanical energy and heat energy are mutually convertible, for a change in the volume of the working substance at the *rate* of $\tau\frac{dp}{d\tau}$ *per unit of the change of volume.*

The symbolic expression of the first law may be as follows: Let T be the number of thermal units transferred to one pound of the working substance (or abstracted from it), N the number of pounds of the working substance, and W the entire work done by the substance on account of the heat absorbed (or done upon the substance in producing heat), then

$$W=J\,.\,NT.$$

But the value of T can be found from this equation only when the entire work W is external. If it be partly internal, the entire work, both external and internal, must be determined by the symbolic expression of the second law, which is, considering that the *rate* may constantly vary,

$$dW=dv\,.\,\tau\frac{dp}{d\tau};$$

$$\therefore\ W=\tau\int\frac{dp}{d\tau}dv.$$

The two laws of thermodynamics may be likened to the two divisions of Mechanics, Statics and Dynamics.

On page 306 of the author's text is the statement: "It is required to find how much of this work is performed by the disappearance of heat," and on page 428 of the last May number of this magazine, reasons are given for canceling the words "of this." But the sentence may mean, "it is required to find how much of this work is performed by the disappearance *of an element* of heat"; for the heat represented by A*e*, Figs. 28 and 29, is an infinitesimal of the heat which disappears during the performance of the work $Av=pdv=U$, and since, in Fig. 29, A*e* ultimately equals *xc*, we have

$$acef=d(Av)=d^2U=dpdv.$$

But $p$ is a function of the actual heat Q, and hence the expression is properly written,

$$\frac{d^2U}{dQ}dQ=\frac{dp}{dQ}dQdv.$$

It should be observed that the heat disappearing is not $\delta Q$, as some have inferred, but it is the difference between the heats for two different isothermal expansions, one being at the constant heat Q, the other at the constant heat $Q+\delta Q$, the amount of the expansions being $dv$ in both cases. In Fig. 28, M*fcd* is the amount disappearing at the constant heat.

Q and MA*cd* at the heat $Q+\delta Q$, for the expansion $dv$, and the difference, or

$$Acef=\frac{d(dU)}{dQ}dQdv$$

is the heat disappearing for an element of the work $dU$, as before shown.

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# PROPOSAL FOR AN AMERICAN ACADEMY OF ENGINEERING.

By WILLIAM KENT, M.E.

Read at the Buffalo Meeting of the American Association for the Advancement of Science, Aug. 20, 1886.

Contributed to Van Nostrand's Engineering Magazine.

Do we need another engineering society? Are not the various American societies, the Civil Engineers, Mining Engineers, Mechanical Engineers, Sanitary Engineers, Electrical Engineers, the Engineers of the Army and of the Navy, the various local societies in Boston, Philadelphia, Pittsburgh, Cleveland, Chicago, St. Louis and other places, and last, but not least, the section of Mechanical Science and Engineering of the American Association enough? What reason is there for the existence of another society?

In 1871 a similar question might have been asked, when only one of the above

named societies was in existence, the American Society of Civil Engineers. What reason, then, for the organization of a new society, the Institute of Mining Engineers? But in that year a small group of men organized that society, and it now numbers over 1,400 members. In 1880 another group of men organized the American Society of Mechanical Engineers, and it now numbers 700 members. All of the other societies above mentioned are also, I believe, well and flourishing. In 1882 I attended a meeting of this section at Montreal, when there were only half a dozen members present. We have no need to-day to ask whether this section is flourishing. As far as I know, all the engineering societies are doing excellent work, and nobly fulfilling the objects of their existence, which objects are, chiefly, to give opportunities for the members of each society to get acquainted, to mutually diffuse information among themselves, and so to increase the knowledge of all, and to increase the already formidable bulk of American engineering literature. So important are these objects that many engineers find it beneficial to join three or four different societies, and to spend a great deal of time and money attending their meetings.

But with all due respect for all the societies above named, not one of them, nor all together can do the work which I think another society, formed on a different model, ought to do for the benefit of the engineering profession. I think the time has now come when we should have another society formed in a different way from any now in existence, and with a different object. My scheme is an ambitious one; parts of it, if not the whole, may be Utopian, but the idea has been growing in my mind for at least two years, getting larger and larger, until I think it is time to unburden myself of it and let some one pull it to pieces if it deserves it, or give form and comeliness to the rough structure as it leaves my hands, if worthy of such treatment.

I look far into the future and I see a society or Academy of Engineering which shall not be strong in numbers—not over 300 or 400, but powerful in influence for good, whose members comprise army and navy engineers, civil, mining, metallurgical, mechanical, electrical, and sanitary engineers, and are all distinguished men in their respective branches, having *done* something creditable in the engineering line as a pre-requisite to membership. Such membership is the highest honor that can be conferred by the profession upon an American engineer, except that of officership in the same academy, and it is an honor that can be conferred only through merit which is appreciated by the majority of the profession, and not through personal favoritism of a nominating committee. It is an honor, moreover, which cannot be withheld from a deserving man by a blackball of one, or seven, or even fifty members. It is an aristocracy based upon intellect and achievement, and yet a democracy in which all are equal, in which majorities rule and minorities are represented, in which each member is a representative of a branch society of lower degree and owes allegiance to it.

In such a society the army engineer could lose his *caste*, and no longer look down on the civil engineer, for both he and the civil engineer would be promoted to a higher caste; yet the army engineer would still be a member of the Army Engineers' society, and the civil engineer a member of the Civil Engineers' society.

With such an academy in existence, the head of the bureau of engineering of the navy, with a political naval advisory board, would not concentrate in themselves all the knowledge necessary to build ships of war, for each would find in the academy other men better posted in shipbuilding than themselves, and would call them in for consultation. The Secretary of the Navy would not need to make a servile copy from the drawings of a Japanese man-of-war, for he would find in the academy men who would design a better one. There would be no necessity for a council of engineering societies to organize and agitate for the public works of the Government to be carried on according to the laws of common sense, for the Committee on Public Works of the academy would be charged by the Government to report what works should be undertaken, and members of the academy, some of them army, some navy, some civil, some mechanical engineers, according to the character of the work in hand, would be in responsible charge of them. The honorable member of Congress in whose dis-

trict is Cheesequake creek, would not log-roll an appropriation for digging out that famous stream, in exchange for a vote in favor of a similar appropriation for some unheard of stream in Minnesota, for Congress would appropriate a round sum to be expended for river improvements under the direction of the academy.

The army engineers would not condemn a system of harbor improvement because it was proposed by a civilian, for army and civil engineers would all be friends together in the academy. A mixed civilian and army and navy board would not be appointed to conduct iron and steel tests, and be given an appropriation one year and then be disbanded the next, for the academy would have in charge a series of tests which would run on steadily for ten or twenty years, with an endowment or appropriation sufficient for the work.

I see the academy meeting once a year, one year in Boston, the next in San Francisco, the next in New Orleans, and so on. A whole week is given to business, papers are read and discussed, but they are papers of national importance. They are scrutinized before being printed, and printed before being read. There is no rubbish amongst them. Committees are appointed to carry on investigations, and appropriations are made for their expenses. One committee is instructed to go to Europe and report on sewage and water pollution; another is to report on ordnance and armor for ships of war; another on reclamation of waste lands, irrigation and forestry; another is to conduct experiments on cylinder condensation of engines; another to redetermine the laws of flow of fluids in pipes; another to experiment with the fuels of the United States, and the best methods of burning them; another is to take up and continue the unfinished work of the late lamented U. S. Iron and Steel Board. A medal is presented to one of the members for a distinguished achievement in engineering, an appropriation is made to one of the members to enable him to complete a costly original investigation. A prize is offered for the best paper on a certain subject, and another for an invention which is considered to be of the greatest benefit to mankind.

The academy is rich. It owns a large fire-proof building in New York City, in which there is the most complete engineering library in the world, and also a museum of models, plans and photographs of important engineering works; a working laboratory of research for the use of the research committees of the academy and others who may be entitled to it; and a hall for meetings which is used by the Civil, Mining, Mechanical and other engineering societies when they meet in New York City.

The academy is interested in the education of the engineers of the future. There is an engineering college with a large endowment, in which all branches of engineering are taught, and according to the terms of the endowment one portion of its board of trustees is elected by the academy, and a committee of the academy is intrusted with the allotment of some of its fellowships and scholarships.

The academy is not a venerable body of fossils and old fogies, for it is constantly being enriched by new blood from the several American societies. It is the foremost body of engineers in the world, and the leading engineers of Europe are proud to be admitted to its membership, as the highest honor the engineering profession has to offer them.

Is such a dream impossible of realization? I think not. Three things are necessary for its fulfillment.

1st. The men.

2d. The organization of these men.

3d. The money.

The men we have. Some are in the army, some in the navy, some in one society and some in another, but they are not all acquainted with each other; they are scattered over the wide country and never meet together. Glance down the list of names of the Civil and Mining Engineers societies, and we see names of men of national reputation and great ability who might be shining lights in a congress of societies, but who also, from their very attachment to the one society of their choice, are strangers to all the others. What a company these distinguished men would make if they could be organized into one body.

The money would be forthcoming if such a body of men were organized. Scarcely a year passes but some millionaire leaves a large sum of money to found some college, hospital, library, art

gallery, manual training school, or other institution of public benefit. The American Association has received sums of money to hold in trust for the prosecution of original research. What better disposition of his money could a millionaire make than to endow the American Academy of Engineering with a trust fund to be applied to its several objects, the founding of a library, a museum of engineering, a laboratory for original research, or a scholarship fund for engineering students? Suppose the academy established and in possession of a working laboratory, would not the national and State Governments be calling upon it frequently for research into questions affecting the public health or safety? and these calls would necessarily be accompanied by liberal appropriations. Of course this matter of money would be one of slow growth. The academy would be poor at first, existing on the fees and contributions of its own members, but money would flow to it as soon as it showed that it had the right men to use the money, and the right kind of organization.

So we have the men and can get the money.

How can we get the organization?

My suggestion, which can no doubt be improved upon, is as follows:

Let the question be agitated in the three American societies, the civil, the mining and the mechanical engineers, and let them appoint a committee of conference to draw up a plan of organization of the academy.

I would suggest to the committee of conference this scheme:

The original members of the academy to be the presidents and past presidents of all the engineering societies of the United States. These men to meet and incorporate the academy. After its nucleus is thus formed it is to grow by accretions of members from the American societies as follows:

Five members to be chosen each year from each of the large societies, the civil, mining and mechanical engineers, and two each from the army engineers, the navy engineers, the sanitary engineers and the electrical engineers, making twenty-three new members to be added each year. The method of selecting these members is the following:

Each active member of each society chooses from the whole list of members of his own society, of not less than five years' standing, a number of names equal to the number to be elected from his society; thus a member of the civil engineers' society chooses five names, and a member of the sanitary engineers' society two names. These he writes upon a ballot which he transmits to the secretary of his own society. Tellers are appointed who select from all the names voted upon those having the highest number of votes, the ten highest from the civil, mining and mechanical engineers' societies, and the four highest from each of the others. The lists of these selected names are then certified to the secretary of the academy, who prints them in a ballot list, each name having opposite it the number of votes it received in its own society. The members of the academy then vote upon these names by scratching out one half of those nominated by each society. Tellers of the academy are appointed to count these ballots and certify as elected those receiving the highest number of votes, the five highest of those nominated by each of the large societies, and the two highest from each of the others. Members elected to the academy have thus to pass through two ordeals; first, they must be among the members receiving the highest number of votes in their own society for the nomination, and second, they must be among those receiving the highest number of votes of the members of the academy. There is thus no nominating committee, no council passing upon nominations in secret conclave, and no blackball.

The above is the outline of the scheme. All I ask for it is a vigorous discussion.

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HYDROGEN IN GLOW LAMPS.—The well-known fact that the carbon filament of a vacuum glow lamp is gradually dissipated by some electric or thermal effect of the vacuum, points to the trial of lamps, in which the vacuum is discarded and its place supplied by an atmosphere of hydrogen, nitrogen, or other gas, which cannot oxidise or burn the filament. Messrs. Siemens Brothers have lately been making lamps filled with hydrogen and they find that these lamps do not become sooty on the inner surface of the glass. Next to a filament, which will remain incandescent in the open air, an envelope which will remain clean and not of itself destroy the filament is a desideratum.

# THE NATION'S GREAT PROBLEM.

By R. H. THURSTON, Director of Sibley College, Cornell University.

An Address delivered at Rose Polytechnic Institute, Terre Haute, Indiana, June 23, 1886.

To the student of history, past and contemporaneous, a wonderful panorama is presented by biologists, and by the historians, of the progress of the race, from those primeval times of which the records are only written in the rocks, and of which the story is only told us by the geologists—from those days which were ushered in by the command, "Let there be light"—up to the days of steam, electricity, and the common school. And in this historical retrospect nothing can be more interesting, nothing can be more suggestive and striking, and nothing can be more seriously impressive, than the continuous succession of mighty social upheavals and revolutions that have made that progress so strangely intermittent, and so apparently defiant of all law as to forbid all attempt at prophecy of the nearest future. Nations rise and nations fall; progression is followed by retrogression; civilization advances great peoples to a high standard of life, in all the arts, and in every field of intelligence, only to yield, later, as a broken reed, and to let Greece, or Rome, or the empire of the Saracens, sink back into barbarism. India once flourished, and is now like dry leaves; Egypt grew as a great banyan grows in the groves of her predecessor; and Egypt falls into decay, hollow in every root, every trunk, and every branch. Italy dominates the earth, and Italy is conquered by the Goths and the Vandals who spread the dark mantle of savagery over her decaying body, and yet transplant the seeds of light to their own homes, where, later, it enlightens the world.

The history of every nation is thus marked by tremendous social changes, sometimes resulting in advancement, sometimes in retrogression, even where the people on the whole, gain in wealth, intelligence, and moral standing. France, best of all, illustrates this proposition, and Great Britain has a history which is almost as remarkable, and is quite as instructive. The people of England, France and Germany have gained in all that makes life worth living, in the material sense as well as intellectually, and yet only through a progress that has been hardly less intermittent than that of the race as a whole. Our own country had its birth in the throes of revolution. In its short life it has already experienced one mighty struggle, the result of which seemed, at more than one time during the strife, likely to be a reversal of the wheels of progress. It is thought, by more than one keen observer of our recent and our present position, that we are at the beginning of, or perhaps in the midst of, a struggle more momentous than any that has preceded.

In every one of these great revolutions, whether accompanied by war or wholly peaceful, whether the strife of nations, the revolution of a people against oppression, or the hardly less trying struggles of a nation of workers during periods of industrial depression or of actual famine, the nations suffer. Hundreds, thousands, sometimes millions, of people struggle for life, and for their children's lives, while the weeks, months, or years, of trial continue; and once they are over, go on contentedly and unthinking, through the succeeding periods of comparative peace and comfort, and into the next period of suffering, apparently without an effort to discover the cause of their misfortunes, or to find a remedy. The great movements of the world go on, continuously and irresistibly, and they are continually being caught in the mechanism of the universe, and bruised and crushed with never a thought of the possibility of escape.

As the globe on which we live, launched into space and whirling steadily on through its vast and endless orbit, with a speed exceeding many times that of the fastest shot from the most powerful modern ordnance, moves ever onward, with an energy that never weakens, and a motion that never slackens, carrying its living freight through the viewless regions of unmeasured space, regardless of any thought, wish, or effort of theirs; so the

race itself launched into life, endowed with an unmeasured and in unmeasurable energy, which carries it on through time with never-ceasing progress, must seemingly ever move forward; but, unlike the suns and their attendant planets, its movement is never unresisted. Its motion is more like that of a flowing stream, vexed by eddies, continually turned from its course by obstructions that it cannot force aside, checked by frictions that never cease, impeded by rocks and shoals that constantly compel it to change its course, to flow faster and shallower here, and deeper and slower there, and often to reverse its direction, turning for the time quite away from its final destination. But its motion cannot cease, nor can it ever turn absolutely and permanently away from its destiny. Vexed or unvexed, it must flow on into eternity.

And here is the Nation's Great Problem: How can humanity, compelled to its course toward the destiny lying away beyond sight or ken in eternity, relieve itself from the vexations of its life? How can progress be made as smooth as it is inevitable? How can the revolutions, the periods of darkness, the time of distress, be avoided? How can the seemingly unnecessary sufferings of weak and unfortunate human beings be relieved? How can progress be made steady and smooth, and easy and fruitful of good to all? How may the wise and the good and the fortunate best aid the less intelligent and evil disposed, the bad and the unfortunate, who suffer because of the perturbations of the world, the spiritual and the material, and how help to prevent those perturbations?

The wisest and best of men have found but one answer to these questions, one solution of the great problem—"Educate the people!" Educate the world in all wisdom. Teach the people a knowledge of as much of the moral and the physical law of the universe as they have capacity to absorb. Teach them that, since they cannot control the laws of nature, they must study to make those laws their servants; and, if they cannot breast the tide, they must make it the means of advancement toward the ends appropriate to their purposes. Teach them to foresee, and to prepare for, the dark days that must some time surely come. Teach them the laws that govern all social and industrial movements; that they may turn the workings of those laws to their own best and real advantage. Give the race moral education, intellectual education, manual education. Prepare them for life in a world in which no one can prosper who does not move on with it, and who does not adapt himself to its ways, and his movements to its progress; in which those who stop, or attempt to move at a lesser speed, inevitably fall.

Civilization is foresight and foreknowledge; the highest civilization is that which sees and best prepares for the remotest future.

What, then, is education? Paley says that "Education, in the most comprehensive sense of the word, may comprehend every preparation that is made in our youth for the sequel of our lives." Education is all of that, and it is more than that. It is coming to be seen to be every preparation made in our youth for the sequel of our lives, and for the rendering of the lives of those about us and those who succeed us more prosperous and more happy. It is the preparation which we are continually striving to make for successfully meeting the greater events of national life, tending to impede or to destroy national growth and progress, no less than for happily passing through individual existence.

The primary object of education is, evidently, to make the individual intelligent, self-reliant, earnest, capable; to give him the means of acquiring such knowledge as is most essential to his success in life, and to prepare him to make the most of such opportunities and advantages as may come to him, to fit him to enjoy life in the highest and best ways, and to help his neighbor to enjoy it with him. It should make him a good, useful, and reliable citizen. It should start him into the path leading into his life's work with such an outfit as should best fit him to pursue that path with most perfect success. Beyond this, it should make him a good citizen in the sense that he should be capable of doing his share in the labor of making the law helpful to the nation at large, and to all other good citizens. It should help him to foresee the future and to provide for it, not only for himself and his own family, but for the nation of which he is a member. It should aid him to make the course of its

history smooth and free from revolutions, industrial crises, or struggles of class with class, whether such strife be within the law or against the law; whether bloody or bloodless. It should so instruct the citizen that the national life may flow on, as a stream through fertile plains, unvexed and unchecked, smoothly, steadily, deep and full, and productive of all good to all men, helping all, harming none, flowing deeper, stronger, more smoothly, through all the centuries.

Our definition of education has been growing through all the past ages, to a more and more definite ideal. We speak of the old and the new; but there is no old and no new; it is all the development of that which is to come. Education, like all other great phenomena of the world, and of the universe, is undergoing evolution constantly, tending continually toward the best for our time, and for the time that is coming. Beginning with the crude ideas of the earlier civilizations, it has been steadily changing—at first speculative, next intellectually gymnastic, later scientific in every division, including not only the physical sciences, but, recently, involving the training of every human faculty, not excepting the bodily senses and organs. Our methods of education have been constantly changing to meet the continually growing and improving ideal. In the days of Aristotle, of Plato, of Socrates, men learn by following the thoughts of other men into region of philosophy far removed from the common events of life; and, in the literature of Greece and Rome, we still present to the student, to-day, the speculative side of education. With the birth of Galileo, the times of Newton, of Gilbert, of Bacon, came the study of the great phenomena of nature, and the reduction of her newly discovered laws to the systematic form which we now recognize as science. With the introduction of scientific methods of study of natural law, of the phenomena of nature, of the sciences thus given shape, came the application of this new form of knowledge to the purposes of common life, and the fruitage of the seed sowed, even in the days of Aristotle, in those first rude attempts at the construction of natural science. The later period saw these departments of human knowledge included in the accepted systems of general education. Finally, the introduction of science, and of applied science, into the schools led to the appreciation, on the part of educators, of the now universally-admitted truth that education not only may, but should, be a means of aiding men in their endeavors to make living easier and more productive of benefit in every-day work and life. Ruskin's three talismans of natural existence—labor, law, courage—are seen to assume our understanding that it shall be intelligent labor, civil law as accessory to the physical and moral laws of the universe and its Creator, and courage to maintain one's own, and his neighbor's privileges and rights—the right being kindly and generously gauged by the law and by the community. Education must now teach this definition.

The gradual evolution of methods and processes in education, as in all cases of social evolution of ideas and intellectual methods, has been a process of broadening and deepening, a process of development that has, as is invariably the case in all such developments, retained the best and the essential of the old, while seizing upon and incorporating the new. The new educations include the old; the new systems are the spine and the marrow of the old, with added stature and increased powers and grasp, with superfluous and "remanent" members and nerve and muscle pruned away, while the essential members are enlarged and strengthened and made more facile and useful. The old standpoint from which the object of education was defined was that of the intellectual gymnasts; the latest standpoint is that of the student of history and of humanity, who recognizes the fact that the "sound mind in a sound body," "the soul of a sage in the body of an athlete," such as Agassiz was said to illustrate, has its use. as well as its ornamental office, and who sees that the greatest good of the greatest number, and the greatest good of the individual as well, are to be secured by the cultivation of the powers of mind and body, with a view to making both of service, in the highest possible degree, to the individual, by helping him to work, however humble, in his place in the world, and to the nation by making its individual citizens capable as well as intelligent. We are to make the most of the man, or

woman, that mind and body, as given by the Creator, are equal to, and then to see that the mind and body, so rendered most fit to occupy the place in the world for which they are intended, get into that place and do the work allotted to them most efficiently; whether that work be delving in the soil or the chanting of a hymn; whether it be spinning or weaving, or fighting for country or freedom, or preaching or praying, making a steam engine or building a house, directing an "industrial army," in the construction of great public works, or making the laws of a nation.

As I have elsewhere remarked, it is a common saying among the wisest and most thoughtful of our wise and thoughtful fellow-citizens that the great safeguard against all such dangers as seem now to threaten our country, and I might add, against the social convulsions that have at intervals rent every form of society, and led to strife and revolutions in every nation known to history, and which have so often interrupted the progress of civilization, is the education of the people. But what is a real education of a people? What is a true education? Is it not the teaching, and especially the training, of the young with a definite understanding of the purposes for which this life is to be lived, and in such a way that they may best accomplish these purposes? Is it not such a method of instruction as shall render them wiser and of better judgment, more skillful and readier in self-adaptation to all the demands that may be made upon them, in the work of a lifetime, in the pursuit, first, of the necessaries, next, of the comforts and blessings, and, finally, of the highest gifts and purest pleasures that life can give, each in order of necessity? It is certainly not the highest education of the few that mainly concerns us, important as that phase of education undoubtedly is, not only to the few, but to the many; but it is the education of the many *well*, that is to say, their education most perfectly, with a view to the use to be made of education by them. The people must be carefully educated with a view to the people's work in life, not so educating them that they cannot strive and struggle with fate, and conquer her, and fight their way onward and upward, to the extreme reach of their powers, we may hope; but, at least, so that they may find themselves well prepared for the work which will certainly be theirs to do at the first, and for the great majority of them the work to which they must buckle themselves through life.

We are to stimulate and cultivate intelligence in the people, in every citizen, offering the best prizes and the greatest opportunities to those who are best prepared to take advantage of them and of the chances coming to them. Education, the best and most fruitful education, must be given to our people, wisely, carefully, persistently, if we would escape the terrible dangers to our nation and to our government which we so often see looming up in the near future, and presaged by a thousand threatening clouds of misrule and lawlessness. The most selfish policy unites with the most noble form of philanthropy to urge us to look bravely and determinedly upon every sign of the possibly gathering storm and adopt promptly and courageously every precaution against it.

Says Emerson, in his "Perpetual Forces":

"As cloud on cloud, as snow on snow, as the bird in the air, and the planet on space in its flight, so do nations of men and their institutions rest on thoughts."

And again he says:

"The world stands on ideas and not on iron or cotton; and the iron of iron, the fire of fire, the ether and source of all the elements is moral force."

True it is that the nations and all their institutions rest on thoughts, and true it is that the world stands on ideas, and that moral force is the basis of all, the foundation of all; and as true is it that the thoughts which we instill into the minds of the youth in process of educating them, and the moral direction which we give, and the moral power which we cultivate during that work of preparation for the work of life, are the basis of all good that comes to the youth, and to the world through him, in later days.

It is said that there are two distinct educations—the old, or gymnastic, which develops the man and teaches him the use of his faculties, and the new, or technical, which teaches him to make use of the powers of mind and body that were given him by nature, and which are improved

by art, to make himself useful to himself and to the world. This is true, and yet it is not strictly true. Both are, or should be, parts of one education of which some may get the one part and some the other; but no man is educated until he has profited by both parts of the one unit. It is said that there is a conflict of studies, and it is oftener said that there is a conflict between great physical and great spiritual truths. The one statement is as incorrect as the other. As God's truths never conflict, so the principles of real education cannot contend one against another. There is no conflict between science and religion, though there may be between the scientific dogmatist and the dogmatic theologian; there is no conflict between the old and the new education, although there often come contests between the self-styled disciples of the one and of the other. We look abroad, over the wide and ever broadening field of human knowledge, and, as educators, it is our duty to cull from this infinity of knowledge, verging into the unknown, but to be known, beyond, so much of fact, truth, law, and of the systems of science, literature and the arts as will best suit our purposes for the time being, and best accomplish the results at which we aim. As knowledge increases, and more and more becomes accessible and useful and desirable, we are compelled occasionally to make a new adjustment of time and labor to the new conditions, and to revise our work and our scheme; but wise men are constantly making this revision, and the education of the moment is being continually ad justed to the needs and the opportunities of the time. In classical training we have found the form of education especially desirable for certain classes in the community, in scientific education that best for another, and in truly technical education that which is needed by still another class. But the really educated man will combine all of these; he will have a training that includes something of each of all the recognized branches of a liberal—in a broader sense than the classical—education, and will have soul and body, intelligence and muscle and nerve, all prepared by systematic cultivation for making the most of life. His intellectual gymnastic education has prepared him for the acquisition of technica knowledge, and for its application, for the rapid and effective acquirement of business experience and wisdom, as his physical gymnastics have made his body capable of exhibiting strength and endurance in the physical work of life. As the one follows the other, in natural sequence, the problem of education divides itself into two parts: 1st, the securing of the best preparatory education; 2d., the finding of the best system of technical and professional training.

In the evolution of the ideal system of education, therefore, we may anticipate many changes in the older systems and older methods, of which the often quoted words of Emerson undoubtedly to a certain extent are true.

Emerson has said: "We are students of words; we are shut up in schools and colleges and recitation-rooms for ten or fifteen years and come out at last with a bag of wind, a memory of words, and do not know a thing. We cannot use our hands, or our legs, or our arms. In a hundred high schools and colleges this warfare against common sense still goes on."

But the indictment is becoming less true each year. As Renan has said in his autobiography, the time is rapidly approaching when the student will give his principal attention to those branches of learning which definitely tend to give him at once disciplinary training and useful knowledge, which both strengthen and interest him. It is asserted that "the time will come when the older educations will no longer be predominant. The more we know of nature the more there will remain to be discovered. The natural sciences offer inexhaustible fields for research; and the truths which they reveal will prove more and more interesting to mankind." "Men of science are becoming more and more important factors in our lives. They are little by little winning the fight against disease; they are giving us facts, and enabling us to found our beliefs on the sure ground of knowledge. Their influence must undoubtedly increase as time goes on; and humanity always reserves its highest honors for those who teach it to do and to know."

It would be, perhaps, wiser to say that, looking out over our whole pantology, it is found that its boundaries are most rapidly extending in the direction of the

natural sciences and the sciences of application. To give the best education, therefore, it is necessary to constantly scan the ever-widening field, and to glean from its whole continually growing area the best for our present purposes. This must evidently include more and more of the newly-gained, the more modern portion, and the older education must be constantly in process of reconstruction to admit the new. There is thus no real conflict of studies; but the modified system compels more care on the part of the teachers of the older branches, and more skill in securing efficient work and in preserving the best, while pruning out the least needed part of the course. Wise men will adjust apparently conflicting interests, so far as they seem to exist, with the sole object of securing the best results of application of the available time of youth. Ordinarily, it should be the aim to first secure the best general education, and next the best possible professional education; but if, as is so usually the case, the student has not time for both, he must combine, with all the greater care, the disciplinary and the professional training in such time as he can give to the work. Thus securing the best education for himself, he is prepared to act his part well when those great social changes, called revolutions, take place, which are the mile stones of the progress of the race.

Technical education is the modern complement of the older, incomplete, academic education. It is simply the introduction into the scheme of instruction of that kind of professional training in industrial departments which has been so long familiar in the professional education of the physician, the jurist, the clergyman. It is the education which the great mass of the people need for the completion of their preparation for their life-work, after their preliminary instruction in the schools.

The ideal education would be such as should fit the citizen for successful pursuit of every desirable object in life, while enabling him to secure the capital needed for its complete attainment and thorough enjoyment. It would begin with the primary instruction demanded as preparatory to the studies of its later periods. The primary education would be followed by so much of secondary education, in the sense in which that term is now generally used, as should give to the youth the essential elements of a truly liberal education, such as should prepare him to continually advance into the unlimited fields of human knowledge; to gain from day to day, through all his after-life, more knowledge and higher learning in every division of science, literature and art; to enter upon the philosophical study of history, the comprehension of comparative philology, of the development of literatures; of the seductive and wonderful problems of mathematics; the no less wonderful principles and strangely beautiful phenomena of the physical sciences; the still more marvelous laws and operations of nature, as illustrated in the living creation; and, more than all, to some comprehension of the moral and the intellectual, sufficient, perhaps, to gain a glimpse of that great spiritual world of which the grandest minds and the loftiest imaginations which the human race has yet produced have never yet been able to grasp more than the most infinitesimal portion. A truly liberal education—and by this I mean vastly more than a strictly classical education, as we have seen—fits man to walk with his Creator in every field, spiritual, intellectual, physical, which the creature's faculties are given him to explore. From this point on, the education of the youth, now becoming mature in mind and body, must be made, usually, even where not before, special. He has been given the means and has been shown the way by which to enter into his wonderful heritage of the universe. Now, because he cannot grasp all, and because he must prepare himself for such complete knowledge of a vocation, and of all which is demanded for its successful prosecution, and because he may undertake a very small part of the work of the world, and that in a very restricted field, he must become a specialist, and must, in this work, confine his time, thought and labor to the acquirement of a profession, or a vocation. This must be the final period of his education; for, after entering upon his chosen life's work, he cannot usually expect to find opportunity to continue his education as an occupation. He must then buckle himself to the task, and take only such rare and short intervals for intellectual pursuits

as may be given him in his hours of rest and of rare leisure. This education, the ideal education, naturally divides itself into three distinct periods, devoted to three equally distinct objects. First comes the primary education, in which the child is prepared to begin the secondary portion of his work, which latter is the real beginning of a true education, of real intellectual acquirement and work; while the third period is that of professional education and training, a preparation for the vocations of life. And such should be the education of every human being, man, woman, or child in this nation.

But we cannot yet hope to see more than a very small proportion of the race, even in the most enlightened countries, pass beyond the first of these stages; and the greater number must for many a century yet, we may well fear, forego even the first. In our own country, fortunately, it rarely happens that a citizen may not, if prudent and industrious, find a way to secure for his children a primary education. A smaller number are able to obtain for their boys and girls special training in trades, or in the professions; and the number who can give their children a truly liberal education is lamentably small. The citizen who is so fortunate as to be able to supplement the primary education of the child by a technical training, foregoing the liberal education which he, probably more than his more fortunate neighbor, would desire to secure for the boy, may to-day well consider himself fortunate. But the numbers of such citizens are increasing year by year, and the technical school, usually distinct from the college, is becoming a recognized factor in our system of education. But the necessities of men compel a breaking up of the ideal system of education, and a setting off of the primary education, the liberal and the technical, each by itself, and each citizen gets what he can or what he chooses. Time may be expected to bring about changes in the direction of advancement, and to lead in the course of generations to the general adoption and acquirement of the ideal education. The ancients endeavored to train the individual; our own tendency is now rather to the acquirement of knowledge; while the real education, the gymnastic combined with the technical, the liberal with the professional, will confer upon the man all the great divisions of human knowledge. This union of all forms of education is not new as a scheme of instruction, though so novel in practice. The Greek aimed to unite all mental with all physical training. Plato would have children trained by the state in order that they should be prepared to do all that the state demands of the citizen. He would teach science as well as philosophy. In the Middle Ages the education of the youth was literary in the cloisters, but it was practical and professional in the castle; and some of the young knights of those strange days were so fortunate as to have the benefit of both kinds of instruction, pursuing the "gentle arts" as well as practicing those of war. Even the monks of the dark ages, however, taught arithmetic, geometry, and astronomy; and every knight in the days of chivalry was desirous of so much knowledge of language and literature, at least, as would enable him to read the tales of errantry, and to make verses complimentary of the beauty of his lady. Among the great universities which arose in the twelfth to the fifteenth centuries, many taught the learning of the professions; and some became mainly professional schools, as Bologna in law, and Salerno in medicine. Luther "led the schoolmaster into the cottage," and laid the foundation of the existing German system of education of the whole people; and Melancthon did his part toward the revival of literary instruction. The reformation of the church and the schools went on side by side. Sturm, Ratke and Comenius, were the leaders in a revolution no less complete and no less important than were those inaugurated by the great ecclesiastics of the preceding generation. John Locke inveighed against current useless knowledge, and insisted upon the inculcation of those forms of mental action which best fit the man for the duties of life; while Milton, pointing out "the right path of a virtuous and noble education," seconded the demand of Comenius, that the "learning of things and of words" should be carried on together. He considered agriculture, architecture, engineering and navigation no less important than the languages, literature and mathematics. He would make

of his men warriors, citizens and athletes, as well as scholars. Matthew Arnold ascribes the wonderful achievements of Prussia during the past generation to the fact that, in the system of education so wonderfully there developed, every man is taught his business on the best plan that can be devised; and it is this which that great author desires to bring about, as well as the education of youth in the humanities. Arnold's cry for better instruction in science and the professions, and the earnest, almost pathetic, appeal of John Scott Russell twenty years earlier, for systematic industrial and professional training, are but the echoes of the voices of many wise men of earlier times. The Marquis of Worcester, two centuries ago, sent out the same warning from the depths of his dungeon, where he had been forced away from his wonderful invention, the "fire engine," the steam-engine as it had been later named, that was echoed again from across the channel by the great mechanic Vaucansen. But the actual institution of a system of technical education was left to the German and French nations within the last century, and upon the great scheme of general and practical, as well as liberal, education by them organized, the strength and wealth, and the intellectual progress of those great nations are based. And thus the seeds sown fifteen and a half centuries ago by St. Basil, of Cæsarea, in whose workships the "poor wayfarers" might learn the essential principles and the methods of practice in the various "pursuits and professions of life," have finally borne fruit in the enriching of nations. A century ago Count Rumford established technical schools for the beggars of Munich; to-day the whole of the German and the French empires are established, socially and financially, very largely upon just such schools; and the English-speaking nations are just be ginning to profit by the precepts of that illustrious tory. The ideal education proposed by the great Descartes is just coming into actual realization, here, among our people, whose habits, customs and traditions are such as may be expected to permit its fullest and most faithful development.

In this development of the modern educational structure, the process has been very like that described by Dr. Whewell, who, in his history of the inductive sciences, says, "The earlier truths are not expelled, but absorbed, not contradicted, but extended; and the history of each science which may appear like a succession of revolutions, is in reality but a series of developments." * * * "Thus the final form of each science contains the substance of each of its preceding modifications, and all that was, at any antecedent period, discovered and established, ministers to the ultimate development of its proper branch of knowledge."

Thus, in education, the development of the latest phase of a continually growing system illustrates the evolution of a more perfect and complete from a less developed and less complete form; and the process of construction has been one of accretion, part by part, the whole assuming a more perfect form as the process continues, until now, as we approach the period of completed growth and enter upon the perhaps final stage of progress, we can at least begin to appreciate the fact that we have here also an illustration of the operation described by the great writer from whom I have just quoted. Some years ago, in tracing the history of the development of the modern steam-engine, I was greatly interested in observing how strictly its growth illustrated this same method. So strongly did this strike me that, in planning the written history, I divided it into the several periods of speculation, of application in several distinct forms, and, finally, a period of refinement. So, it would seem, we are now brought, in the history of education, to a "period of refinement," in which all the elements of the complete system being present, the efforts of nations are directed toward their selection, arrangement, and mutual adjustment, to form a complete and symmetrical whole of maximum efficiency and as perfectly as possible adapted to the purposes which the experience and the wisdom of a world has found essential. In studying this development and this final unplanned but no less systematic reconstruction of the whole, it is interesting to observe how generally the several reformations, and the various attempts to secure an ideal beyond and outside of existing methods and schemes, have been inaugurated by individuals,

and how seldom by governments. The Conservatoire des Arts et Metiers, at Paris, was founded upon the basis of the collections of that inventor and wonderful mechanic, Vaucanson. L' Ecole Centrale was established by Dumas, Pictet, Ollivier and Lavallée, the latter supplying the funds, and the three professors the no less needful, and even more rare, contributions of knowledge, genius and organizing talent. In these latter days we observe the same characteristics of this development of the perfected form of education, and nowhere more prominently than in the United States. The organization of the institutes of technology and the various technical and trade schools in this country—and of the academic schools as well, I should add—has largely been the work of private philanthropy and patriotism. We rarely see a reference to their growth that is not accompanied by an acknowledgment of our indebtedness, as a nation, to men like Chauncey Rose, like Ezra Cornell, Hiram Sibley, Edwin A. Stevens and Asa Packer, like Sheffield and Lawrence, and Case and Van Renselaer, and many others scarcely less distinguished as benefactors of the country and of their race. It is a comfort to find so many of our craft enrolled on this splendid list, who have splendidly supplemented that grand gift of the nation to the people, on which are founded the "land-grant colleges."

Another thought comes to the student of this recent phase of our social life and growth. The period of refinement upon which we have now entered is one of adaptation of the work of instruction and its methods to specific purposes, of application to definite lines of work, having as definite and as special objects in view. The process of refinement is thus, in this sense, a process of specialization, just as, in every industrial department, the later developments have all been in the same direction of exact production and reproduction of exceedingly nicely-defined, exactly shaped and precisely measured objects for the use of man. It is thus that we have come to the period of expansion of special schools and special departments of technical application of the laws and principles of the mathematics and of the natural sciences. Just as in a watch factory, we have one machine to turn out a pinion, another to make its arbor, one to produce a pallet and another to make the plate; so in our education of youth, we now have one school to give special instruction in civil, and another in mechanical engineering; one to give the aspirant for distinction in natural science his training, and another to make him a physician, a lawyer, or a minister of the Gospel. For these are all technical schools. Each has for its office the preparation of the young man who is about to go out into the world to conquer what it may have in store for him, in such a manner that he may best, most promptly, most economically and most efficiently, acquire the practical knowledge, and most readily and fully profit by the experience which is thus offered him. The term "technical" will not bear restriction to our schools of engineering or of applied science, in the sense in which that restriction is commonly attempted. The older schools of law, of medicine, and of divinity, and their young relatives, those of engineering and the trades, all belong to one category, and come under the common designation, properly, of technical schools. The technical school is thus seen to be the result of that specialization which is everywhere making all processes, all departments, all forms of industry, whether manual or intellectual, more efficient and more productive. Every phase of modern civilization and of modern life illustrates this refinement of all arts, and of all social processes by specialization; and the technical school is merely one of its latest examples.

I have sometimes asserted that the work of technical instruction in the arts must, for effective action and maximum efficiency, be still further specialized, and that the solution of that educational problem which now most interests us must be found in the subdivision of the work of the technical schools relating to the constructive arts, which should be distinguished by a natural system into three principal kinds—the manual training school, the trade school, the school of engineering. The first should be planned with a view simply to the instruction of boys—and girls—in the use of the various tools used in the constructive arts: the second should teach the trades, and their theory and fundamental principles of practice, as well as the ap-

plication of the skill acquired in the first kind of school, while the last and highest grade should be so organized and conducted that the student, now mature and well grounded in the fundamental studies, shall be able to secure a good knowledge of the principles of applied mathematics and of applied science, as illustrated in the practice of the designing and of the constructing engineer, and a knowledge also of the methods of practical work, so far as they may be taught and illustrated in the school; while he is also given a good idea of the relations of the several trades to the professional work of the engineer. In the manual training school the boy learns to use his hands and handle tools; in the trade school he learns the method of some trade; in the school of engineering he learns the principles of design and the ways in which the trades may be made useful to secure a result set forth as to be attained. It is not at all the fact, as at least one of my friends among the critics has asserted, that this is a system of caste distinction; it is merely a system of careful adjustment of means to ends, and of furnishing the learner just the knowledge that he at the instant desires, in the most accessible and available possible form. It is the construction of an educational machine to turn out the kind of product that is wanted, and the citizen has perfect freedom of choice as to which kind of apparatus he may avail himself of. The boy who is best fitted to learn one trade, and to excel in that, is very likely not the boy who is best adapted to profit by the opportunities especially offered by the school of engineering. The young man who is to become a designer of costly and complicated machinery, and who should therefore go through the last mentioned school, might prove a failure as a workman at the trade in which the former may become distinguished above all his fellows. Each possesses, often, a distinct sort of talent, and is best fitted for his special line of professional work.

Thus, by a slow and fitful perhaps, but never-ceasing progress, we are evolving the best system of education of the youth of our country and nation. Technical education is the apparently last phase in this evolution; but the evolution of the various general and varieties of technical education is likely to continue to be the essential feature of further social progress for many years, and probably for generations still to come. This process of development of the best means of preparing the individual and the race for its work in the world will undoubtedly continue to improve in its efficiency and in adaptation to the needs of the people until, and we may hope in a not distant future, every citizen shall have the opportunity to prepare, through a very perfectly devised system of education and training, for his work, and for his mission of good in the world. Technical training will reach, each year and each generation, further down toward the lowest strata of society, until, finally, every man, every woman, and every child shall have the privilege of receiving a real education, such as is best suited to the best interests of the individual. Every vocation, every position in life, will be taken into this beneficent scheme of advancement of humanity.

What we see around us, on every hand, great as is the work, splendid as is the fruitage of this modern tree of knowledge, a fruitage wholly good, is but the seed of a mighty harvest, yet to come, such as it is probably impossible for the most sanguine among us fully to realize, either in relation to its immediate, or its more important remoter, results.

I have said that we are to hope for a development of real and complete, a true and a vivifying education that shall in time enable the world to avoid the terrible consequences of those great political and social convulsions which have from prehistoric times been the milestones of human progress toward better things. Every human being may be expected to be affected, if not absolutely controlled, by four sets of conditions, and their resulting influences. Politically, the citizen is more or less under the control and in the power of the government under which he happens to live, and is subject to laws which bear, with a force he cannot control or evade, upon every condition affecting his life, his liberty and his endeavors after happiness. Socially, he is tied into an industrial system in which he may have a certain amount of freedom of movement and of choice of vocation, but he is nevertheless as firmly bound as a part of the system as, politically, he is secured under a code of law. He must

do his part, both as a citizen, as one unit in the national whole, and as a worker, one unit in the great industrial body. Another tie of the average citizen is that of the family, and he is controlled and commanded by this bond no less firmly than by the others. Finally, every individual is more or less governed by those personal interests which mainly affect him alone, and make up his life as an individual, those which relate to his personal life, apart from the lives of those about him, and which are not absolutely controlled by his relations to others, such as good and bad habits, the traits of the individual character.

A perfect system of education will prepare the individual to make the most of life for himself, to enjoy its pleasures, to gain its rewards and to absorb all that life can offer him as an independent existence. It will prepare him to care effectively for his family and to readily gain for them all that is necessary for their comfort and happiness in this life. It will prepare him to take his place in the industrial system, and to do his work in the world so efficiently and with such satisfaction to himself and others that he may contribute the most possible to the stock of good things possessed by the world and the race. It will, finally, prepare him to take his place in the political structure, and to do his duty as a citizen in such a manner that the government to which he owes allegiance shall be made more efficient by the fact of his existence.

And thus the nation's great problem will be finally solved. Humanity, trained and educated, conscious of and obeying, whilst making the highest use of, all moral forces and of all moral law, intellectually developed to a maximum of strength, wisdom and foresight, physically prepared to force every natural agent to its own purposes, possessing in its mighty self-acquired powers, genii more numerous and more powerful than ever Aladdin knew, compelled in its course toward the destiny leading it away on into eternity, may yet be able to evade all such vexations and trials as have, in the eternity of the past, fretted its course, and may make progress as smooth as it is inevitable. The revolutions, the periods of darkness, the now often-recurring times of distress, will be found to have causes which are ascertainable and removable, political causes dependent upon conditions that a wise statecraft may comprehend, and assisted by intelligence, wisdom and patriotism on the part of the people, may remove; industrial conditions which a better knowledge of and a wiser dealing with the laws of labor and of supply and demand will adjust so that progress shall be made steady and smooth and easy, and fruitful of good to all; social causes, which the education and training of the people and the preparation for the duties of life may, in the main, dispose of, leaving every honest and well-meaning citizen safe against periodical distress, capable of securing for himself and for those dependent upon him all that is needed to make life comfortable and enjoyable, and to enable him to do his part in relieving the weak and unfortunate, whose number, generation by generation, will become a smaller and smaller proportion of humanity. Thus it is, we may hope and firmly believe, that the great perturbations of the mighty current of human progress may gradually become less and less frequent and less violent, and the ideal education bring to the whole world more and more completely all the possibilities that mortals do most desire. Nations, no longer exposed to destructive blasts from the cloudy regions of ignorance and passion, will not flourish only to decay but will grow indefinitely, stronger, wiser, better, each helping the other toward a better future; progression will be continuous; governments will govern for the people; the industries will yield all that the world needs and demands, without crushing the workers, and all men will come to an intelligent use of lives into which will be incorporated so much of leisure as is needed for the soul's best interests, and the intellect's highest aspirations. We may even anticipate that the wealth of the world will be, by wealthy men, more and more directed into channels in which it shall most and best advance the noblest desires of the race. We may be sure that the great men who have been the pioneers in the work of introducing what is needed to complete the structure and to aid the evolution of the ideal education, and whose monuments we see around us, will have a following which, as time passes, will become continually more and more numerous, through all coming cen-

turies, until a great army of these fortunate citizens shall find most glorious work in making life better and brighter for their fellows; it will be to them, more than to all others, that the race will offer the greatest honors through all the coming years, as to those who have done most to make bright its course and its destiny, and to solve the great problem of the nations.

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## RECENT ADVANCES IN SANITARY SCIENCE.

From "Nature."

"HYGIENE," in the words of the late Professor Parkes, "is the art of preserving health; that is, of obtaining the most perfect action of body and mind during as long a period as is consistent with the laws of life. In other words, it aims at rendering growth more perfect, decay less rapid, life more vigorous, death more remote." The art of preserving health is correlative with the science of prevention of disease, since perfect health means the absence of disease and of tendencies to disease. Hygiene is thus the art of preserving health and the science of preventing disease; and in taking into account recent advances in sanitary science we must consider recent acquisitions in our knowledge of the origin, causes, and spread of disease, more especially of those diseases known as "preventable," as well as the methods of improving the natural conditions or social relations surrounding us, which are instrumental in preserving health and counteracting disease.

The etiological relations of all diseases are a subject of interest to the sanitarian, but those which have received the most attention of recent years, and in which the most striking advances of knowledge have either already been made, or are imminent in the near future, are perhaps Asiatic cholera, typhoid or enteric fever, diphtheria, and phthisis or tubercular disease of the lungs. The mode of origin and spread of Asiatic cholera has attracted great popular attention, both on account of its possible introduction into this country from infected districts of the Continent, and from the alleged discovery by Koch of a *spirillum* or *comma-Bacillus* asserted to be the specific cause of this terrible disease. The Report of the Government Commission, consisting of Drs. Klein and Heneage Gibbes, who visited India in 1884 with the object of undertaking researches into the etiology of Asiatic cholera, has lately appeared, and in this Report the conclusions arrived at by Koch from his own researches are very directly traversed. This Report, too, has received a very cordial support from a committee consisting of many eminent physicians and physiologists, which was convened by the Secretary of State for India for the purpose of taking it into consideration. It must be apparent, however, to any one who makes an impartial study of the literature of the subject, that, if Koch's organism has not yet been proved to be the actual cause of the disease, it has been proved to differ from all other organisms asserted to be identical with it, from the fact that its growth in various nutrient media is characteristic, and serves to distinguish it from all other organisms. As far as our knowledge at present extends, difference in manner of growth in nutrient media affords as just a basis for distinction between micro-organisms as difference in microscopical appearance or other morphological characteristics. Koch's comma-Bacillus is therefore diagnostic of the disease, and this fact has now placed in the hands of medical men the power of at once recognizing a true case of Asiatic cholera, the isolation of the organism from others in the choleraic discharges and its cultivation in suitable media being alone needed. The results of Koch's researches, whether fully accepted or not, have not affected, nor are they likely to affect, the measures on which reliance alone can be placed for the prevention of outbreaks and spread of the disease. In the words of the committee before alluded to, "Sanitary measures in their true sense, and sanitary measures alone, are the only trustworthy means to prevent

outbreaks of the disease, and to restrain its spread and mitigate its severity when it is prevalent. Experience in Europe and in the East has shown that sanitary cordons and quarantine restrictions (under whatsoever form) are not only useless as means for arresting the progress of cholera, but positively injurious."

The view that typhoid fever cannot arise *de novo*, but is always propagated by a specific contagion from a previous case of the disease, is steadily gaining ground, as the number of epidemics where the disease has been definitely traced to specifically polluted air or water increases. In many other cases, although the specific pollution has not been definitely proved, the probabilities in favor of such a view have been very great. No micro-organism has yet been found which can lay claim to be regarded as the specific contagion of the disease, but we are in possession of so many facts concerning the mode of origin and spread of this disease, that any discovery of that nature would probably not greatly affect the measures now taken for its prevention.

The etiology of diphtheria has lately received very careful study, but so far without the attainment of any results capable of exact formulation. It is not a disease invariably dependent on insanitary conditions, such as typhoid fever is, but that such conditions favor its spread and severity is more than probable. The far greater comparative frequency of diphtheria in rural districts than in large towns in this country is well known, and has been attributed to the presence in the air of the latter of the products of coal combustion. This view appears the more probable seeing that Continental cities, where wood and not coal is chiefly used as fuel, enjoy no such comparative immunity from the disease. Excessive moisture in the air of a house, whether arising from defective construction of the walls or roof, or from a water-logged soil, are conditions very often associated with diphtheria. The fact also that the disease is most prevalent in the damper seasons of the year, when vegetable matter is undergoing decay and fungus life is most active, favors the theory that the specific contagium of this disease is a mould or fungus, which flourishes most strongly in a damp and smokeless air. It is a remarkable fact that diphtheria is sometimes associated with scarlet fever in one epidemic, the two diseases appearing to be interchangeable; but this is a subject that requires further elucidation. The contagion of diphtheria is extremely persistent and long-lived, clinging with great pertinacity to infected articles, so that every article which is likely to have become contaminated requires very thorough disinfection, preferably by heat. There can be no doubt that school attendance is often a chief factor in the propagation of the disease amongst children.

Koch's discovery of the *Bacillus tuberculosis*, a micro-organism now proved to be the specific contagium of tubercular disease in men and animals, has placed tubercular phthisis in the category of contagious diseases. A peculiar disposition or tendency, whether hereditary or acquired, is no doubt wanted to enable the germ to take up its habitat in the human lung, but the fact that this idiosyncrasy can seldom be definitely recognized renders great caution necessary both on the part of members of a family in their association with a consumptive relation, and of hospital authorities in admitting into a general ward cases of tubercular disease, or of massing together into one institution patients in every stage of the disease. The Bacillus is constantly present in the sputum and probably in the breath of phthisical patients, and this points to the necessity of free ventilation of living and sleeping apartments, and disinfection of soiled articles of clothing and furniture. The external conditions which, of all others, cause a predisposition to consumption are, a damp subsoil, causing excess of moisture in the air, and the constant breathing of an atmosphere vitiated by human respiration. It has been asserted that tubercle can be propagated from animals to man by the consumption of diseased meat, or, in the case of the cow, from the milk of a tuberculous animal. Further proof is required before we can accept such an hypothesis, but there is nothing improbable in such a mode of conveyance of the disease, especially in the case of children with a tubercular predisposition.

Besides the diseases which we now know to have been propagated through the agency of milk—enteric fever, scarlet fever, diphtheria, etc., in which the in-

troduction of the morbid matter is accidental, the milk serving only as a means for its conveyance and perhaps for its growth—there is a complaint fairly definite in character, which has been attributed to the consumption of the milk of cows suffering from foot and-mouth disease. Here the morbid quality is inherent to the milk as taken from the cow, and is not due to an accidental introduction. The symptoms described in the epidemics recorded are fever, vesicular eruptions on the lips and in the throat and mouth, and enlargement of the glands of the neck. During the prevalence of foot-and-mouth disease, all milk taken by a household should be boiled before consumption. In view of the many dangers which threaten us through the agency of milk, it would perhaps be advisable, especially where children are the chief consumers, that this precaution should be always adopted; at least until the sanitary authorities in towns have the power of inspecting and controlling the farms and dairies in the country from which the chief part of the milk-supply is derived.

The possibility of the transmission of the contagion of small-pox for considerable distances, not exceeding one mile, through the air, has been warmly supported. There are many facts in favor of such a view, and its great probability will be seen from the following considerations. The contagion is almost undoubtedly a micro-organism of the class Bacteria, but as it has not yet been isolated and identified, we are unaware if it is capable of spore-formation or not. The spores of Bacteria can resist external agencies—heat, cold, drying, and antiseptics—to a much greater extent than the fully formed organisms, and it is probable that those diseases in which the contagion remains dormant for long periods are transmitted through spores capable of existing for long periods outside the body. But in small-pox it is not necessary to rely upon spore-formation to support theories of aerial transmission. The contagion as given off from the body of the patient is inclosed in minute epithelial scales and dry pus accumulations. Here, protected from the air and from external destructive agencies, it may be wafted as a minute dust through the air, to descend at considerable distances. That the radius of infection from a small-pox hospital as a center does not exceed a mile may be due to the great dilution of the contagion as it is diffused through greater distances than a mile from its center of origin, the hospital. The observations of Dr. Miquel, at the observatory of Montsouris, near Paris, have shown the number and variety of solid particles which are carried in the air, and the immense distances which some of them, as pollen and spores, may be presumed to have traveled. An educated public opinion will soon, if it does not already, regard small-pox hospitals as possible centers of infection, and will insist on their removal outside inhabited areas.

The compulsory notification of infectious diseases to sanitary authorities, either by the householder in whose house the case occurs, or by the medical attendant, or by both, has been adopted in numerous provincial towns during the last five years. This measure has done much to furnish the authorities with early information of the occurrence of infectious disease which would not otherwise have been obtained, and such information has doubtless enabled the sanitary officials to stamp out many an epidemic in the bud, which might otherwise have reached large dimensions. The more universal adoption of a measure of compulsory notification in our large towns is urgently needed.

In the domain of domestic sanitation the advances of recent years have been mostly limited to the practical applications of sound principles already acquired to the carrying out of works of construction, drainage, or water-supply of the dwelling. Houses built for the use of the well-to-do classes (not those of the speculative builder) in recent years will most generally be found to be planned and fitted on modern sanitary principles. Thorough ventilation of the drain and soil pipe, disconnection of the waste-pipes of baths, sinks, and lavatories, and of the overflow-pipes of cisterns from the drainage system, are now understood to be necessaries of modern life. A break in the connection between the house drain and the public sewer by means of a manhole chamber and water-seal or trap, though not considered necessary or desirable by all, is

now very usually practiced. We cannot doubt that the air of a public sewer is sometimes the means of disseminating disease, and any method which practically excludes such a source of danger from our houses is one to be encouraged. As knowledge extends, the simplest form of apparatus is found to be the best; many of the more complicated kinds of traps and contrivances for excluding sewer air are now discarded by builders and architects for those simpler forms which are equally effective.

In the matter of water-supply, the belief is steadily gaining ground that a water once polluted by sewage cannot be regarded as safe for drinking purposes. Safe it may be so long as filtration on the large scale is efficiently performed, but any failure to thoroughly filtrate and aerate the water in times of epidemic visitation might be attended with disastrous consequences, even supposing that filtration through sand and gravel is destructive of disease organisms or their spores. The introduction of a constant supply of water into towns, in the sense that cisterns and receptacles for storing water are no longer necessary, has been of great benefit—especially in the poorer parts of towns, where water stored on the premises is usually highly contaminated.

Of the scientific witnesses who were examined before the Royal Commission on Metropolitan Sewage Discharge, nearly all were in favor of the principle of separation of the rainfall from the sewage. "The rain to the river, the sewage to the soil." In view of the ultimate disposal of the sewage, the advantages of the "separate method" are very great, and would now probably lead to its adoption in any new scheme of sewerage for a town where the circumstances are favorable. From the public health point of view, it is also desirable to have impermeable pipe or brick sewers of small size, so that contamination of the soil by leakage into it of the contents of sewers may be avoided. In any such scheme of sewerage it must not be forgotten that not only are channels on the surfaces of the streets and roads required to convey away surface water, but pervious drains laid in the subsoil are absolutely necessary in the health interests of the town to keep the subsoil water at a permanently low level. For the disposal of the sewage, the value of a regular daily flow, and the elimination of the necessity in times of heavy rain, of dealing with an enormous and uncontrollable volume of dilute sewage, must be obvious. The surface waters of towns are certainly not clean, but where the streets are efficiently scavenged they are free from taint of human excretal refuse, and fit for admission into the rivers which nature intended as drainage channels of the surrounding high lands.

The extreme importance of thoroughly ventilating sewers, is now very generally understood. Pipe sewers require as much ventilation as brick sewers, although the absence of deposit on the smooth internal surfaces of the pipes, and their consequent freedom from smell due to decomposition of deposited organic detritus, originally led to the belief that ventilating openings were not required in pipe systems of sewerage. It was not until Dr. Buchanan showed in the case of Croydon that the absence of proper ventilation in the pipe sewers of that town was in all probability instrumental in aiding the spread of enteric fever, that the opinion of engineers on this matter underwent a change. Displacement of air in pipe sewers of small diameter is greatly more sudden than in brick sewers of larger diameter, and it is plain, says Dr. Buchanan, that "means of such ventilation are wanted more numerously in proportion as the displacements of air may be local and sudden." Openings into sewers from the street level are still regarded as the best practicable means for the admission of fresh air, and the exit of sewer air. Charcoal trays, Archimedean screws, and other contrivances for purifying the issuing air, or hastening its exit, are now generally abandoned as useless and inconvenient.

The purification and utilization of the sewage of towns is a subject of much importance both in its public health and commercial aspects. The idea, so long entertained, that town sewage could by various methods be made to yield a manure which would give rise by its sale to an enormous profit, is now exploded. The highest degree of purification, we now know, can only be attained on land naturally suitable from its porosity and other properties, and artificially prepared

by extensive under-drainage. The agents which purify sewage in its passage through soil, by converting the nitrogenized organic matters into inorganic salts —nitrates and nitrites of the alkaline and earthy bases, and ammonia—have been discovered to be bacterial microorganisms, resident chiefly in the superficial 18 inches of soil, and far more abundant in some soils than in others. Sewage farming has been ascertained to be profitable, under suitable conditions. The sewage must flow from the town to the farm by gravitation—the cost of pumping will neutralize profits from the sale of farm produce: a part of the farm must be laid out as a filter bed, so that the sewage, when not required on the cultivated land, or when so dilute from the presence of storm waters as to be inapplicable, may be purified on a small, very porous area, by the process of intermittent downward filtration. Very few growing crops are benefited by the application of sewage, except the various kinds of grasses, and of these such enormous quantities can be produced that, unless converted into "silage," or utilized on the farm in the production of stock and dairy produce, they may be expected to result in a loss, from the absence of any demand for such large quantities at all periods of the year.

In this country, the sewage farm at Birmingham is probably the best example of what has has been done to solve a most difficult problem by the application of sewage to land. Here, the sewage is first freed from its suspended matters by a process of precipitation, a proceeding necessary not only to prevent warping of the land with offensive solid matters, but also to withdraw the metallic salts and acids incidental to the sewage of a manufacturing town, which would be injurious to vegetation. Even this magnificent example of dealing satisfactorily with the most difficult municipal problem of modern times is eclipsed by the city of Berlin on the Continent. The sewage farms at Berlin have successfully dealt with the sewage of 887,500 people —nearly twice the population of Birmingham—whilst London is still allowing to run to waste an enormous amount of valuable material, at the same time polluting a river—the highway of its commerce—to an extent never previously dreamt of.

Processes of precipitating sewage by chemicals are now known to exert only a partially purifying influence. The best process yet discovered can do little more than free the sewage from its suspended matters, allowing all the dissolved constituents of sewage—by far the most valuable portion, agriculturally and chemically—to pass away in the effluent. Lime dissolved as lime water, sulphate of alumina, and perhaps proto-sulphate of iron, taken together and added to the sewage in the proportion of not more than 10 to 15 grains to the gallon, are the best, most economical, and most effective precipitants. Other more valuable substances, added to the sewage with the view of increasing the value of the precipitated sludge or manure, are in large proportion lost in the effluent water, and as they do not assist precipitation, might just as well be added to the sludge afterwards, if fortification is required. Half-a-crown and no more is the value per ton of the precipitated solids of sewage. This value will generally pay for the cost of their carriage a mile or so in agricultural districts, but no further.

A great improvement in dealing with the semi-liquid sewage sludge has been lately effected. The sludge containing over 90 per cent. of water was formerly allowed to dry in the air or in a drying chamber, and a most intolerable nuisance resulted. It is now possible by means of hydraulic filter-presses to convert the semi-liquid sludge into solid cakes containing 40 to 50 per cent. of water, and in this form it is innocuous to the senses, and can be readily conveyed away by cartage.

The knowledge already acquired demands that now, and in the future, the sewage of towns should, whenever possible, be utilized on land in the production of crops or dairy produce; failing this, the sewage should be freed from its solids by precipitation, and subsequently purified on land laid out as filter-beds, efficient purification, and not the production of crops, being alone aimed at. If application to land is impossible, then precipitating processes alone must be relied on, and where the sewage can be turned into the sea, and effectually got rid of without nuisance, there it may be allowable to waste valuable matter which cannot be utilized except at a cost destructive of all profits from its utilization.

# INVESTIGATION INTO THE STRENGTH OF STEEL AND WROUGHT-IRON GIRDERS.*

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THE girders experimented on were all beams with single-plate webs having flanges composed of angle-bars, and two or more layers of plate.

The paper commences with some explanatory and introductory matter, and proceeds as follows:

On the 23d of February, 1877, in the works of the firm of Harkort, at Duisburg, Hochfeld, a riveted longitudinal beam was placed on two supports, and weighted on the center until rupture took place. The beam rested near its extremities on wrought-iron rollers. The pressure on the center of the top flange was applied by a lever 31 ft. 2 in. long, with a ratio between the arms of 1 to 29. By means of a screw at the fulcrum, the lever could be kept in a horizontal position during the deflection of the girder. Lateral deflection was prevented by four angle-irons which supported the horizontal flanges sideways.

The scale-pan at the extremity of the lever was slowly and carefully loaded; the girder stood the test well until the calculated tension in the extreme lamina had reached 12.7 tons per square inch (20 kilograms per square millimeter). Up to that load the observed deflections were less than those calculated, but with the above strain they became equal to it. When the stress had reached the supposed limit of elasticity with a calculated tension of 15.9 tons per square inch (25 kilograms per square millimeter) a peculiar snap was heard, followed by a similar report a second later, after which the girder broke through the middle with a loud noise. The fracture showed a clean, bright metallic surface, without any blemish which could explain the unexpected failure.

On the 19th and 20th of March two longitudinal girders of the same form were tested in a similar way. To distribute the pressure more evenly, a cushion measuring 6.56 ft. by 1 ft. $2\frac{1}{2}$ in. (2 meters by 370 millimeters), made of felt, oak, and iron plates, was placed under the test load on the girder. A snap was heard when the first of these girders was loaded to a calculated tension of 15.2 tons per square inch (24 kilograms per square millimeter). The lower flange of one of the bottom table angle-bars was fractured. No exceptional brittleness or hardness could be inferred from the appearance of the fracture.

The strength of the third girder proved to be even less. A calculated tension of 6.3 tons per square inch (10 kilograms per square millimeter), was successfully supported, but two reports were heard at a tension of 7.6 tons per square inch (12 kilograms per square millimeter). The deflection then was but small; the fracture could not easily be found, and the experiment was proceeded with. When the tension reached 11.7 tons per square inch (18.5 kilograms per square millimeter), another report was heard, and at 12.7 tons per square inch (20 kilograms per square millimeter), a rent was discovered in one of the lower angle bars. A tension of 14.1 tons per square inch (22.2 kilograms per square millimeter), caused the lower flange plate to tear with a report. At 17.8 tons per square inch (28 kilograms per square millimeter), the two lower angle-bars broke, and the bottom flange was ruptured in a second place at 2.62 ft. (800 millimeters) distance from the first fracture. With 21.5 tons per square inch (33.9 kilograms per square millimeter) tension, the lower flange plate and angle bars were fractured for the third time. The girder, with its lower flange broken in several places, bore the slowly-augmenting load until a strain of 24 tons per square inch (37.8 kilograms per square millimeter) had been reached when total fracture occurred. Immediately after this, parts of the broken

* The original appeared in the Tijdschrift van het Koninkliik Instituut van Ingenieurs, 12 Feb., 1881, and contains ten plates, besides numerous tables. The MS. of Mr. Siccama's complete translation, with all the plates, diagrams, and tables, are in the library of the Institution.

girder near the fracture were drilled out and submitted to tests in compression and tension. These last gave satisfactory results on the whole, indicating an ultimate strength of 38 tons (60 kilograms) to 47.6 tons (75 kilograms per square millimeter) per square inch. The elongations amounted to a maximum of 21 per cent. and a minimum of 13.5 per cent., and the contraction of the sectional area varied between 26 and 41 per cent. Some of the rivet heads were cut off to ascertain whether the rivet holes had been properly filled. This proved to have been the case.

From the 11th to the 14th of April, 1877, three steel longitudinal beams were tested at the Union Works, near Dortmund.

The beams were supported at their ex tremities on steel rollers, resting on piers of masonry, and were loaded by dead-weights laid on a platform suspended from the beams by four rods. In order to place the weight on the platform slowly and without shaking, the rails, which served as weights, were first laid over an iron beam placed on each side, and arranged to be lifted or lowered by means of screws. The lifting or lowering never exceeded a rate of $\frac{3}{4}$ in. per minute. Four angle-irons were fixed in order to prevent the platform swaying sideways. Lateral deflections of the tested beam were also guarded against by angle-irons fixed vertically. The deflection in the center was observed on the bottom flange by direct measurements, and on the top flange by means of a special apparatus designed to magnify the readings.

The loading was regulated so as to cause calculated consecutive tensions in the extreme lamina of 6.3, 9.5, 11.4, 12.7, 15.2, 16.5 tons per square inch (10, 15, 18, 20, 24, 26 kilograms per square millimeter). After this tension had been reached, the stress was increased by 1.27 ton per square inch (2 kilograms per square millimeter) at a time, to 25.4 tons per square inch (40 kilograms per square millimeter), after which the gradual increase was at the rate of 0.63 ton per square inch (1 kilogram per square millimeter) at a time. Up to a tension of 17.8 tons per square inch (28 kilograms per square millimeter) the load was completely lifted off, after the deflection had been taken, by means of the screws. Above this limit the beam was totally unloaded at every 6.34 tons per square inch (10 kilograms per square millimeter) increase only in order to save time. All weights causing a tension of over 19 tons per square inch (30 kilograms per square millimeter) were left on for some minutes before adding to them. The three girders tested stood a tension of 21.6 tons per square inch (34 kilograms per square millimeter), and carried a load of 57.7 tons (58,588 kilograms) without any unfavorable symptoms being observed. The deflections agreed pretty well with the calculations. With a tension of 21.6 tons per square inch (34 kilograms per square millimeter) on the first girder, a snap was heard, and a rent discovered on the lower flange plate. With a tension of 24.1 tons per square inch (38 kilograms per square millimeter), the girder broke in two, the lower angle-bars being torn in two or three places.

The second girder tested stood a tension of 24.1 tons per square inch (38 kilograms per square millimeter). When the stress had increased to 25 tons per square inch (40 kilograms per square millimeter), the platform was found to be unevenly loaded. Before it could be lifted, previous to readjustment, a snap was heard, and a rent found in the lower angle-bars on the over-weighted side of the platform. Reports were heard twice after resuming the experiment, and a second fracture was found in the lower angle-bars; the girder broke in two when the calculated tension had reached 27.9 tons per square inch (44 kilograms per square millimeter).

In testing the third girder, the first report was heard just before the tension of 24.1 tons per square inch (38 kilograms per square millimeter) was reached. No fracture could be found, but the complete fracture followed with a tension of 26 tons per square inch (41 kilograms per square millimeter).

The surfaces of the fractures were those characteristic of good ductible steel. Strips were drilled from near the fractures, and tested for toughness and ductility. The strength amounted to 34.9 and 43.5 tons per square inch (55 to 69 kilograms per square millimeter), the elongation 7 to 19.5 per cent., contrac-

tion 12 to 45 per cent. on the sectional area.

The next beam, forming one of the cross girders of a bridge, was consecutively weighted till 478 rails had been placed on the platforms, and a tension had been reached of 21.6 tons per square inch (34 kilograms per square millimeter), without any alarming symptom being observed; the actual surpassed the calculating deflection, however, to a considerable extent. As soon as the total load, amounting to 144.8 tons (147,034 kilograms), had been imposed, and the tension had attained 22.9 tons per square inch (36 kilograms per square millimeter), the girder broke in two with a loud report. A rent in a lower angle-bar and a crack in the vertical web were discovered. The rent of the web-plate showed a fine fibrous fracture. This was the first experiment in which a total fracture occurred before warning snaps or reports were heard.

The dimensions of the cross girders had been calculated on the understanding that the extreme lamina were not to be strained beyond 6.34 tons per square inch (10 kilograms per square millimeter). The four steel girders tested at Dortmund broke when the calculated strain amounted to three and a-half times this tension. The ultimate strength of the steel was found to be over 38.1 tons per square inch (60 kilograms per square millimeter). Whereas, wrought-iron girders bear a load in the center without breaking or showing signs of shearing in the rivets, till the calculated tension in the extreme lamina approaches the limit of absolute strength; riveted steel beams break when the calculated strain reaches only half that due to the direct tenacity of the steel.

The results of the steel tests thus proved very disappointing. The different authorities on iron and steel manufacture declared that they had encountered phenomena which they could not explain, and it was determined to extend the experiments by means of some rejected girders of larger dimensions, which could be cheaply obtained. These were made of soft steel, of hard steel, and of wrought-iron, and it was also determined to ascertain the difference between girders bolted and riveted together. Accordingly, the following beams were experimented on: Twenty longitudinal girders intended for the bridge across the River Waal at Nymegen. The component parts of three of these girders were annealed before riveting, while two of the girders were not riveted, but bolted. Three cross-girders, three riveted girders of hard steel of the same dimensions as the longitudinals; three riveted girders of soft steel as above; three riveted iron girders as above.

For hard steel, a minimum resistance against tension of 47.6 tons per square inch (75 kilograms per square millimeter) was prescribed, and an elongation on fracture of at least 14 per cent. The requirements for soft steel were a maximum resistance to tension of 31.7 tons per square inch (50 kilograms per square millimeter), and an elongation of fracture of not less than 25 per cent. During the investigation, the question arose as to whether it would be practicable to anneal the riveted steel girders without injuring them. From the steel manufacturers in Westphalia no satisfactory answer could be obtained, consequently an investigation into this important matter became necessary, and one of the pieces of a girder broken in testing was used. It had a length of 13 ft. 6 in. (4,128 millimeters), and was not much deformed. On the top and bottom flange plates center lines were marked, and the width was measured on each side of these at distances 10 in. (25 centimeters) apart. All rivets were proved by means of a hammer and found perfectly tight. The girder was then laid on its side in a roomy annealing furnace, which had been heated for thirty-six hours, and was considered to have attained a temperature of 1,112° Fahrenheit (600° C.). Care was taken to prevent sagging by packing with stones. The furnace was opened for about twenty minutes, while the girder was inserted and packed. To prevent unequal cooling, the furnace was fired for five minutes after closing the doors, after which all openings were bricked up, and all cracks and joints were thoroughly luted with clay. These operations occupied forty-five minutes. The girder was left for sixty hours in the furnace, and was by that time completely cooled. It was then taken out and laid on the supports, on which it had rested during the marking of the center lines.

The girder proved to be warped over its full length; the top and bottom flange-plates were bent, and deviated respectively $20\frac{1}{8}$ in. (51 millimeters), and $5\frac{1}{8}$ inches (16 millimeters) from the original center line. The web was buckled in several places. The rivets were again tested by the hammer and found tight. On cutting off one of the rivet heads a slight layer of dust was found between the plate and the rivet head. With other rivet heads this phenomenon was not observed. The red lead, with which the girder had been painted, was partly burned, and partly remained in flakes adhering to the metal. The deformations were so great and numerous that it was considered as demonstrated that, even if fixed or strutted during annealing, no satisfactory results could be expected.

The results of the investigations are collected in tables, and represented graphically.

It will be seen, with regard to the wrought-iron girders, that the deflection increased in direct proportion to the load, till a tension in the extreme lamina of 16.6 to 17.1 tons per square inch (26 to 27 kilograms per square millimeter) was reached. This rate of deflection did not cease when the girder was again submitted to test, after having been previously loaded up to a tension of 19 tons per square inch (30 kilograms per square millimeter), and then unloaded, and a permanent set was observed of $\frac{5}{16}$ inch (4.18 millimeter). Up to this limit the deflections of the three girders agree very closely. At 17.1 tons per square inch (27 kilograms per square millimeter) the deflections were equal to those calculated, but beyond this limit the first exceeded the last in increasing measure. At 11.4 tons per square inch (18 kilograms per square millimeter) a slight permanent set (0.3 millimeter) was observed; this increased a little (to 1.08 millimeter), with a tension of 15.9 tons per square inch (25 kilograms per square millimeter), to $\frac{5}{16}$ inch (4.18 millimeters), with a tension of 19 tons per square inch (30 kilograms per square millimeter); and to $\frac{8}{8}$ inch ( 10 millimeters), and $1\frac{5}{16}$ inch (49 millimeters) with 24.12 tons per square inch (38 kilograms per square millimeter). The three girders resisted perfectly till a tension of 19.7 tons per square inch (31 kilograms per square millimeter) was imposed, but soon after some rivet-heads in the middle of the girders began to manifest displacement, which increased with the tension, the rivets gradually cutting into the flange-plates and webs. With 22.2 tons per square inch (35 kilograms tension per square millimeter) the compressed bottom flange,* which was supported laterally by the vertical side-stays, began to deflect laterally between the stays. In addition, the beginning of a rent was observed in two rivet-holes in the top flange plate of one of the girders. With 24.1 tons per square inch tension (38 kilograms per square millimeter), the limit of strength seems to have been reached. The little rent before mentioned was followed by a similar one in an adjacent rivet-hole of the flange-plate. When 24.6 tons per square inch (39 kilograms per square millimeter) tension was attained failure commenced, and a grinding rustling sound was heard repeatedly, At first the upper flange-plate opened. and was followed a few moments after by the second and third; the two angle-bars broke next, two dull reports were heard, the web-plate cracked, the rent widening slowly to $\frac{1}{16}$ inch (2 millimeters.

With a tension of 24.1 tons per square inch (38 kilograms per square millimeter), the three girders were visibly deformed. The top and bottom flanges showed lateral deflections. The plates of the bottom flanges between the rows of rivets were buckled vertically; the web-plates were bulged in many places. The pressure having been continued, the girder lost its symmetry, its resistance was destroyed, and the pressure-gauge indicated a continuously diminishing tension. The deflection did not decrease with the removal of the load. The top and bottom flanges showed considerable elongation and compression, amounting, in a length of four rows of rivets, or 1 foot (320 millimeters) to $\frac{7}{16}$ inch (11 millimeters) and $\frac{1}{8}$ inch (3 millimeters) repectively. Two vertical angle-bars secured to the web at a distance of 2.9 feet from each other (40 millimeters), receded from each other at the top $\frac{1}{16}$ inch (18 millimeters), and approached each other the same distance at the bottom.

Bending and tensile tests made on the

* Many of the girders were tested by hydraulic pressure applied upwards in the middle, hence the bottom flanges were often in compression.

several parts of the girders show a resistance against tension of 24.1 tons, and 25.4 tons per square inch (38 to 40 kilograms per square millimeter) an elongation at the point of fracture of 12 to 25 per cent., and a contraction of fractured area of 11 to 35 per cent.

Not a single unfavorable phenomenon was observed during these experiments on wrought-iron girders. The results corroborate sufficiently the accuracy of the calculations usual for determining their strength and deflection; they show that the admitted maximum tension gives a factor of safety of 5, that wrought-iron endures without detriment, shaping, drilling and riveting, and that, in being built up in the usual way, it makes a girder which leaves nothing to be desired in respect of strength and flexibility.

The steel girders, ranging in length from 17.6 feet (5,359 millimeters) to 20.3 feet (6,187 millimeters) show with tensions of 3.2 tons, 6.3 tons, 9.5 tons, 12.7 tons per square inch (per square millimeter of 5, 10, 15, and 20 kilograms) very similar deflections; the extreme variation amounted to only $\frac{1}{32}$ inch (0.8 millimeter) in one case. After unloading, the deflections nearly disappeared. In the case of three girders, 27.9 feet (8,500 millimeters) long, the deflections at the above indicated tensions showed variations ranging to $\frac{1}{8}$ inch (3.03 millimeters). The permanent sets, after a tension of 12.7 tons per square inch (20 kilograms per square millimeter) amounted to $\frac{1}{32}$ inch (1.01 millimeter). Also, with a tension of 13.3 tons per square inch (21 kilograms per square millimeter) in eighteen steel girders, the ratio between deflection and load remain constant, and the top flange-plate of one girder was torn with a tension of 11.4 tons per square inch (18 kilograms per square millimeter). Under a tension of 14 tons per square inch (22 kilograms per square millimeter) a snap was heard, but no crack was found. In another case one top angle-bar was completely, and the top flange-plate partly torn under a tension of 13.6 tons per square inch (20 kilograms per square millimeter). Again, a tension 15.2 tons per square inch (24 kilograms per square millimeter) was sufficient to destroy the top flange-plate and two angle-bars of another girder. On reaching the supposed limit of elasticity, corresponding to 16.5 tons per square inch (26 kilograms per square millimeter) in the case of another beam, a report was heard, and the top flange-plate showed a tendency to move over the plate just underneath it.

After unloading, all the girders showed a small permanent set (varying from 0.06 millimeter to 1.41 millimeter). The deflections observed were, as a rule, smaller than those calculated in the fifteen lighter girders, but those in the three heavy girders were greater. No unfavorable symptoms were observed with a tension of 17.1 tons per square inch (27 kilograms per square millimeter), but under calculated tensions of 17.8 tons, 18.4 tons and 19 tons, up to 31.1 tons per square inch (28, 29, 30, etc., up to 49 kilograms per square millimeter) one or other of the girders was seen to be partly or wholly torn. The weakest girder succumbed at a tension of 20.3 tons per square inch (32 kilograms per square millimeter). Seven girders broke below 25.4 tons per square inch (40 kilograms per square millimeter); ten girders failed while the calculating strains were between 25.4 tons per square inch and 31.7 tons per square inch (40 kilograms and 50 kilograms per square millimeter). One single girder answered expectations, and showed no fissures or rents before the calculated strain in the extreme lamina amounted to 37.5 tons per square inch (59 kilograms per square millimeter). From each of the examined girders strips were taken and tested by bending and stretching. On the whole, the results were satisfactory. The resistance of tension in the direction of the fibers amounted to a maximum of 54.6 tons per square inch (86 kilograms per square millimeter), and to a minimum of 24.6 tons per square inch (39 kilograms per square millimeter). The greatest and smallest elongation observed were 25 and 5 per cent. The contraction on the sectional area varied from 49 to 11 per cent. Also the plates and bars bent cold gave satisfactory results.

The two experiments on steel girders put together with bolts contribute valuable information about the usual joining and riveting. The flange-plates, angle-bars, and web-plates of these girders were placed in position, and sufficiently held together by a few bolts to enable the

rivet-holes to be drilled right through the several thicknesses of metal. All stretching and compression was carefully avoided. The bolt-holes were drilled slightly conical and were fitted with bolts of the same shape. Washers were placed under the nuts, which were screwed home without any special strain. The two girders, under slowly increasing loads, showed regular deflections a little less than those calculated, and the deflections agreed well with those of the other steel girders, until a calculated strain of about 19 tons per square inch (30 kilograms per square millimeter) was reached. With continued increase of load, the deflections increased at a higher rate, and with a tension of 22.9 tons per square inch (36 kilograms per square millimeter) the values exceeded those calculated. No snaps or rents were observed. The bottom flange of one of the girders showed incipient lateral deflection with a tension of 22.9 tons per square inch (36 kilograms per square millimeter), and this deformation slowly increased. The second girder, which was of greater length, remained longer in good condition, and only lost shape under a tension of 31.7 tons per square inch (50 kilograms per square millimeter). The deformations were greater and more irregular than those of the iron girders described before. Whether these more favorable results were owing to bolting instead of riveting cannot be decided with certainty. The results of the following six experiments seem to demonstrate that riveting does not necessarily cause harm. Six Bessemer steel bars $\frac{3}{16}$ inch (49 millimeters) thick and $2\frac{9}{16}$ inch (6 8 millimeters) wide were drilled through in the middle with two holes $\frac{13}{16}$ inch (21 millimeters in diameter). One of the holes was then filled with a steel rivet in the usual way. The bars were then tested for tension, and they all broke through the hole not riveted with a tension of 39.4 tons to 40 tons per square inch (62 to 63 kilograms per square millimeter). In the vicinity of the bolts not a vestige of splitting or rending could be found.

The annealing of the different parts of the girders before riveting did not answer expectations, the tests being, in fact, the least satisfactory. The top cover-plate and angle-bars of the three girders were torn with a tension of but 9.5 tons, 10.8 tons, and 12.7 tons per square inch (15 kilograms, 17 kilograms, and 20 kilograms per square millimeter). The tension of 3.2 tons per square inch (5 kilograms per square millimeter), had barely been reached in one of the girders when the deflection exceeded the calculated quantity. In the two other girders, this took place with a tension of about 14 tons per square inch (22 kilograms per square millimeter). The girders broke with a calculated tension of 14.6 tons, 16.5 tons, and 17.8 tons per square inch (23 kilograms, 26 kilograms, and 28 kilograms per square millimeter), after several premonitory signs of failure. No explanation has been given for these exceptionally unfavorable results. The annealing was performed in the usual manner and with all care. The tests were made during summer. The steel was of ordinary quality. The strips taken from the web plates of the broken girders after the experiments gave, on being tested, an ultimate strength of 32.4 tons and 33.0 tons per square inch (51 kilograms, 52 kilograms per square millimeter), those taken from the cover plates resisted a tensile strain of 29.2 tons, 31.7 tons, and 34.9 tons per square inch (46 kilograms, 50 and 55 kilograms per square millimeter). The elongations before fracture varied between 8 and 21 per cent. with one exception, when a cover-plate seemed to have been burned. The contraction on the sectional area amounted to from 27 to 41 per cent. The metal was generally granular on the fractured surface, but could be bent cold in a satisfactory manner.

The experiments on the three hard steel girders gave surprisingly favorable results. The deflections agreed completely, and increased uniformly with the load, remaining always a little below that calculated until an estimated strain of 34.9 tons per square inch (55 kilograms per square millimeter) was reached in the extreme fibers, and with this tension the two upper angle-bars of one of the girders broke. With an increased load, this beam broke at a tension of 43.2 tons per square inch (68 kilograms per square millimeter). The second girder tore, without previous damage, when the calculated strain amounted to 37.5 tons per square inch (59 kilograms per square

millimeter). It is remarkable that the top flange-plate showed a rent of $\frac{5}{16}$ inch (8 millimeters) wide, while in the web-plate only a small fissure could be found near one of the rivet-holes. In these three girders no motion of the rivets or cutting into the plates whatever took place. The third girder withstood a tension of 43.2 tons per square inch (68 kilograms per square millimeter); the experiment had then to be stopped, owing to signs of warping.

Strips taken from these three hard steel girders gave a resistance against tension of from 51.4 tons to 54.6 tons per square inch (81 kilograms to 86 kilograms per square millimeter), an elongation before fracture of from 9 to 15 per cent., a contraction of from 24 to 36 per cent.

It must be borne in mind that the steel in these girders was made purposely for the experiment, that great trouble was experienced in the manufacture before the material satisfied the different requirements, and that, therefore, it cannot be considered as a fair trading specimen, nor does it compare favorably with wrought-iron. When the wrought-iron girders were loaded till the strain in the extreme lamina amounted to 86 per cent. of the ultimate strength, or to 80 per cent. of the tensional resistance, deformation, indicating the approach of the limit of endurance, began to show, and failure did not occur suddenly, but by gradual yielding.

In the steel girders, fracture occurred suddenly, when the strains reached 73 per cent. of the ultimate strength and 66 per cent. of the extreme resistances to tension. The power of resistance beyond this point was of small value.

The deflection of the iron and the hard steel girders was equal until a strain of 16.5 tons per square inch (26 kilograms per square millimeter) was reached. Above this limit the deflection in the iron girders was the greater.

On the experiments on three soft steel girders, the following remarks may be made. The girders show deflections uniformly increasing with the load, until a strain of 12.7 tons per square inch (20 kilograms per square millimeter) was reached. After unloading, the permanent set was very slight (from 0.66 millimeter to 0.76 millimeter). After 14 tons per square inch (22 kilograms per square millimeter), the observed deflections exceeded those calculated, and these differences increased rapidly with the load. With a strain of 17.8 tons to 18.4 tons per square inch (28 and 29 kilograms per square millimeter), local bulges and deformations began to show, and some displacement of rivet-heads was noticed. A considerable deformation of the bottom flanges and bulges in the web-plates followed shortly after. When a calculated strain of 22.2 tons per square inch (35 kilograms per square millimeter) had been reached, the girders were considerably deformed, and the readings of the hydraulic gauge indicated the collapse of the girders.

Test samples showed a resistance to tensional strain of from 26.7 tons to 31.1 tons per square inch (42 kilograms to 49 kilograms per square millimeter), an elongation of from 12 to 24 per cent., and a contraction on the sectional area of from 42 to 50 per cent.

Though these results are not unfavorable they are not so good as those obtained from iron girders. The deflections of the steel girders were greater, the deformations and bulgings originated at an earlier period and were more irregular. The material for these girders was also manufactured specially for these experiments.

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[Note.—It cannot fail to strike the reader of the above abstract that the quality of steel used in experiments was very irregular, and quite different from steel used for structural purposes at the present time in this and other countries. —W. A.]

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A New Alloy of Aluminium.—The applications of aluminium are now considerable, and M. Bourbouze, a French physicist, has added to their number by employing an alloy of the metals with tin for the internal parts of optical instruments, in place of brass. The alloy he employs consists of ten parts of tin and 100 parts of aluminium. It is white like aluminium, and has a density of 2.85, which is a little higher than that of pure aluminium. It is, therefore, comparatively light, which is an advantage for apparatus where lightness is desired. It can be soldered as easily as brass, without special means, and it is even more unalterable than aluminium to reagents The attention of electrical instrument makers should, therefore, be called to it, especially for apparatus of a portable character.

# SPECIFIC GRAVITY OF LOW-CARBON STEEL.

By F. LYNWOOD GARRISON, F.G.S.

Transactions of the American Institute of Mining Engineers.

As the specific gravity of low-carbon steel seems to be attracting considerable attention as a means of determining the quality and value of the metal, I give here a few of the results of a long series of experiments recently made by me. The object of the experiments not requiring more than approximate correctness in the third place of decimals, the extreme pre cautions to obtain accuracy which are sometimes used in determining specific gravity were not observed. But each piece of metal was carefully cleaned to remove scale, rust, dirt, etc., thoroughly dried, and then weighed in air, all weighings being carefully repeated. The balance used was one of Troemner's finest, and sensitive to one-tenth of a milligram. Before weighing in distilled water, care was taken to remove, as far as possible, the air enclosed in the pores of the metal.

The pieces of metal were suspended by means of fine silk thread, a correction of course being made for the weight of the silk. Care was taken that the water in which they were weighed should be always at the same level, and, as far as pos sible, at the same temperature.

The determinations were made upon the following samples:

1. Clapp-Griffiths steel bolt, 3 inches long and $\frac{1}{4}$ inch diameter, containing 0.08 carbon and 0.36 phosphorus.

2. Clapp-Griffiths steel bolt, 5 inches long and $\frac{1}{2}$ inch diameter, containing 0.08 carbon and 0.50 phosphorus.

3. Bessemer steel bolt, 3 inches long and $\frac{1}{4}$ inch diameter, containing 0.08 carbon.

4. Bessemer screw, containing 0.10 carbon.

5. Bessemer screw, containing 0.10 carbon.

6. Wrought-iron bolt, 6 inches long and $\frac{1}{2}$ inch diameter.

7. Wrought iron bolt, 5 inches long and $\frac{5}{8}$ inch diameter.

No. 1 was divided into three parts, head, shaft, and nut. No. 2 was similarly divided, but the shaft was further divided transversely into five sections, each an inch long. No. 3 was divided like No. 1. Nos. 4 and 5 were each divided into head and one-inch sections of shaft. No. 6 similarly furnished head, six sections, and nut. No. 7. head, five sections, and nut. The specific gravity of each of these parts was determined separately, with the following results:

| No. | 1. | 2. | 3. | 4. | 5. | 6. | 7. |
|---|---|---|---|---|---|---|---|
| Head | 7.822 | 7.886 | 7.800 | 7.796 | 7.759 | 7.705 | 7.638 |
| Shaft, or 1st section | 7.849 | 7.800 | 7.853 | 7.785 | 7.758 | 7.669 | 7.568 |
| 2nd section | ..... | 7.799 | ..... | 7 859 | 7.813 | 7.676 | 7.556 |
| 3d section | ..... | 7.834 | ..... | ..... | 7.832 | 7.662 | 7.575 |
| 4th section | ..... | 7.834 | ..... | ..... | ..... | 7.667 | 7.577 |
| 5th section | ..... | 7.836 | ..... | ..... | ..... | 7.622 | 7.569 |
| 6th section | ..... | ..... | ..... | ..... | ..... | 7.625 | ..... |
| Average of head and shaft | 7.8350 | 7.8315 | 7.8269 | 7.8133 | 7.7905 | 7.6609 | 7.5805 |
| Nut | 7.670 | 7.600 | ..... | ..... | ..... | 7.584 | 7.640 |

The nuts were excluded from the above averages as probably manufactured from different pieces of metal.

It seems from the above that the density of the metal is considerably affected by shop-manipulations; for, as will be noticed in the case of the large Clapp-Griffiths steel bolt and the Bessemer steel

screws, the specific gravity is greater at the heads and at those parts on which the threads are cut. This sudden alteration in density can hardly be accidental, and must be caused by the pressure exerted in cutting the threads and forming the heads pushing the metal fibers closer together and thus decreasing the size and number of air cavities between them.

But so far as the screw-threads are concerned, the contrary seems to be the case with the wrought-iron bolts; for it will be noticed, their density gradually decreases from the head down. And in this respect No. 3 also is anomalous. It will be noticed, moreover, that my results are considerably below the figure of 7.854, adopted by Mr. Miller in his paper on this subject (*Transactions*, vol. xiv., p. 583), for boiler-plate steel containing 0.14 carbon.

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## ELECTROMOTORS FOR RAILWAYS.

From "Industries."

We have drawn attention to the question of electrically-propelled trains on railways, and pointed out that there were three great difficulties which must be overcome before electric railways can come into general use. The greatest of these difficulties is that of the conductors. We must generate the electric current at some fixed points situated in proximity to the line, and we must convey it to the train by means of a conductor fixed along the line, and so arranged that a metallic contact piece attached to the train and sliding along the conductor establishes at all times electrical connection between the generating dynamo and the motors in the train. Now, if the distance between the two is considerable, large portion of the electrical energy contained in the current is wasted in the conductor itself, and little remains to do useful work in the train. It is true that we can reduce this waste by making our conductor of very large cross section, and employing copper for it, which conducts electricity very freely; but in so doing we increase the first outlay too much. We can also reduce the waste by working with a comparatively small current of very high electromotive force. An experiment in this direction has lately been made by M. Marcel Deprez, who attempted to transmit power over a distance of 35 miles by means of an electric current of close upon 6,000 volts electromotive force. Practically, the experiments were a total failure, and this is mainly due to the high electromotive force employed. At the present moment, no electrical engineer would consider it safe to employ for transmission of power more than 1,000, or at the outside 1,500 volts, and at that pressure the limit of economical working is only a few miles. An electric railway of several hundred miles in length would therefore have to be fed with current from a large number of generating stations placed along the line every few miles, and the outlay for buildings and plant would in this case be excessive. It must also be borne in mind that where the current has to be generated by steam power, which in flat countries would always be the case, the total coal bill for the electrically-worked line would be about twice as heavy as that for ordinary locomotive traction, because the double conversion of mechanical energy into current, and back into mechanical energy, entails considerable loss. To fix ideas, let us suppose we have a tolerably level line which is to be worked by electricity, and that with the pressure of 1,000 volts, which we consider safe, we can transmit power economically to a distance of five miles. In this case, the distance from one generating station to the other would have to be about ten miles. As the train travels along the line, one station after another will be called upon to supply it with power, each station becoming idle when the train has passed beyond its reach. But if the traffic can be so arranged that the interval between successive trains is less than the time required to travel ten miles,

the machinery at the generating stations will never run idle; and beyond the usual reserve for cases of accident, no more power need be supplied than is actually represented by the total number of trains running simultaneously. This would be the case on a metropolitan railway, where trains, especially if short and provided with ample starting power, could succeed each other at intervals of one or two minutes. It would be perfectly safe to work such a line electrically at a pressure of 300 to 400 volts, and if the generating stations were placed every half mile or every mile along the line, the aggregate power which would have to be provided in these stations, would not materially exceed the power represented by the total number of locomotives which would otherwise have to be used to work the same line on the train system. In this case, the cost of the plant necessary for generating the current and the working expenses would not be disproportionate, if compared to the power actually utilized on the line. But if the line be very long, and the traffic comparatively light, the cost of the generating plant would be excessive, and electric traction, with power derived from fixed steam engines, and conveyed to the trains by conductors, could under no circumstances replace ordinary locomotive traction. We have spoken above of the difficulty of transmitting the current from the dynamo to the train, and we have shown how this difficulty limits the application of electric traction to short lines with very heavy traffic. There is, however, another alternative, and this consists in having no conductor at all, and in working the motors by means of secondary batteries carried in the train. No experiments on a large scale have as yet been undertaken to show whether this system is or is not commercially feasible. A few tramcars have in this and some continental countries been tried, which were propelled by secondary batteries and electromotors; but no railway has yet been worked on this plan. It is quite possible that, as accumulators are improved, they may be used with advantage on long level lines; and if water power be available for working the charging dynamo, the system may, even in point of economy, be found to compete successfully against steam locomotives.

We spoke in the beginning of this paper of three great difficulties which stand in the way of electric propulsion. The greatest, that of the conductor, has been at length discussed. The other two are, first, the excessive weight of electromotors, and secondly the difficulty of efficient and economical regulation of speed. When speaking of the weight of a motor per horse-power, it is always necessary to take into consideration also its speed, total power, and efficiency. It will be self-evident that the weight per horse-power will be the smaller, the quicker we arrange the motor to run, and the more we press it electrically, regardless of efficiency. But this is not a satisfactory way of reducing dead weight. What we want is a motor of high efficiency (at least 85 per cent.), moderate speed, and little weight. Now, these conditions are to a certain extent conflicting. There are motors in the market which give over 90 per cent. efficiency; but their speed is comparatively high, and they weigh from 2 to 2½ cwt. per horse-power. On the other hand, motors can be had which only weigh 60 lbs. per horse-power; but their efficiency is only about 60 per cent., and their speed excessively high in comparison with the power given out. It will be clear that the larger the motor the lower should be its speed. Thus a 5-horse motor running at 1,000 revolutions a minute, must be considered to be of moderate speed in comparison with a 10-horse motor running at 900 revolutions a minute. Yet even the speed of the former is inconveniently high, because it necessitates a complicated speed-reducing gear if applied to the axle of a railway coach. If motors could be designed weighing about 50 lb. per horse-power, and of sufficiently low speed to be applied direct to the axle of railway wheels, a great step would have been taken in the development of electric railways. Another very necessary improvement is, some device by which the speed and power of electromotors can be varied at will, without wasting power by the introduction of artificial resistances. Such a device would be equivalent to the expansion gear in a steam engine, and would be necessary, not only for economic reasons, but also for the purpose of having the speed of the electric train under as perfect control as that

of an ordinary train drawn by a steam locomotive. We recommend these considerations to those of our readers who are practical electricians. The man who solves these problems will be sure to benefit his profession generally, and to reap himself large benefits from his invention.

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# ON NEW APPLICATIONS OF THE MECHANICAL PROPERTIES OF CORK TO THE ARTS.

A Paper read at the Royal Institution of Great Britain by WILLIAM ANDERSON, M. Inst., C.E., M.R.I.

From "Nature."

It would seem difficult to discover any new properties in a substance so familiar as cork, and yet it possesses qualities which distinguish it from all other solid or liquid bodies, namely, its power of altering its volume in a very marked degree in consequence of change of pressure. All liquids and solids are capable of cubical compression, or extension, but to a very small extent; thus, water is reduced in volume by only 1/2000 part by the pressure of one atmosphere. Liquid carbonic acid yields to pressure much more than any other fluid, but still the rate is very small. Solid substances, with the exception of cork, offer equally obstinate resistance to change of bulk; even india-rubber, which most people would suppose capable of very considerable change of volume, we shall find is really very rigid.

I have here an apparatus for applying pressure by means of a lever. I place a piece of solid india-rubber under the plate and you see that I can compress it considerably by a very light pressure of my finger. I slip this same piece of india-rubber into a brass tube, which it fits closely, and now you see that I am unable to compress it by any force which I can bring to bear. I even hammer the lever with a mallet, and the blow falls as it would on a stone. The reason of this phenomenon is, that in the first place, with the india-rubber free, it spread out laterally while being compressed longitudinally, and consequently the volume was hardly altered at all; in the second case, the strong brass tube prevented all lateral extension, and because india-rubber is incapable of appreciable cubical compression, its length only could not be sensibly altered by pressure.

Extension, in like manner, does not alter the volume of india-rubber. In this glass tube is a piece of solid round rubber which nearly fills the bore. The lower end of the rubber is fixed in the bottom of the tube, and the upper end is connected by a fine cord to a small windlass, by turning which I can stretch the rubber. I fill the tube to the brim with water, and throw an image of it on to the screen. If stretching the rubber either increases or diminishes its volume, the water in the tube will either overflow or shrink in it. I now stretch the rubber to about three inches, or one-third of its original length, but you cannot see any appreciable movement in the water-level, hence the volume of the rubber has not changed.

Metals when subjected to pressures which exceed their elastic limits, so that they are permanently deformed, as in forging or wire-drawing, remain practically unchanged in volume per unit of weight.

I have here a pair of common scales. To the under sides of the pans I can hang the various specimens that I wish to examine; underneath these are small beakers of water which I can raise or lower by means of a rack and pinion. Substances immersed in water lose in weight by the weight of their own volume of water; hence if two substances of equal volume balance each other in air, they will also balance when immersed in water, but if their volumes are not the same, then the substance having the smaller volume will sink, because the weight of water it displaces is less than that displaced by the substance with the larger volume. To the scale on your left hand is suspended a short cylinder

of ordinary iron, and to the right-hand scale a cylinder of ordinary copper. They balance exactly. I now raise the beakers and immerse the two cylinders in water; you see the copper cylinder sinks at once, and I know by that that the copper has a smaller volume per pound than iron, or, as we should commonly say, it is heavier than iron. I now detach the copper cylinder, and in its place hang on this iron one, which is made of the same bar as its fellow cylinder, but forced, while red hot, into a mould by a pressure of sixty tons per square inch, and allowed to cool under that pressure. The two cylinders balance, as you see. Has the volume of the iron in the compressed cylinder been altered by the rough treatment it has received? I raise the beakers, immerse the cylinders, the balance is not destroyed; hence we conclude that although the form has been changed the volume has remained the same. I substitute for the hot compressed cylinder one pressed into a mould while cold, and held there for some time, with a load of sixty tons per square inch; the balance is not destroyed by immersion, hence the volume has not been altered. I can repeat the experiments with these copper cylinders and the result will be found the same. Extension also is incapable of appreciably altering the density of metals. I attach to the scales two specimens of iron taken from a bar which had been torn asunder by a steady pull. One specimen is cut from the portion where it had not been strained, and the other from the very point where it had been gradually drawn out and fractured. The specimens balance, I immerse them, you see the balance is not destroyed; hence the volume of the iron has not been changed appreciably by extension.

But cork behaves in a very different manner. I place this cylinder of cork into just such a brass tube as served to restrain the india-rubber and apply pressure to it in the same way; you see I can readily compress the cork, and when I release it it expands back to its original volume: the action is a little sluggish, on account of the friction of the cork against the sides of the tube. In this case, therefore, a very great change in the volume of the material has been easily effected.

although solids evidently do not change sensibly in bulk, after having been released from pressures high enough to distort them permanently, yet, while actually under pressure, the volumes may have been considerably altered. As far as I am aware, this point has not been determined experimentally for metals, but it is very easy to show that india-rubber does not change.

I have here some of this substance, which is so very slightly lighter than water, that, as you see, it only just floats in cold water but sinks in hot. If I could put it under considerable pressure while afloat in cold water, then, if its volume became sensibly less, it ought to sink. In the same way, if I load a piece of cork and a piece of wood so that they barely float, if their volumes alter they ought to sink.

In this strong upright glass tube I have, at the top, a piece of india-rubber, immediately below it a piece of wood, and below that a cork; the wood and the cork are loaded with metal sinkers to reduce their buoyancy. The tube is full of water, and is connected to a force-pump, by means of which I can impose a pressure of over 1,000 lbs. per square inch. The image of the tube is now thrown on the screen and the pressure is being applied. You see at once the cork is beginning to shrink in all directions, and now its volume is so reduced that it is incapable of floating, and sinks down to the bottom of the tube. The india-rubber is absolutely unaffected, the wood does contract a little, but not sufficiently to be visible to you or to cause it to sink. I open a stop-cock and relieve the pressure; you see that the cork instantly expands, its buoyancy is restored, and it floats again. By alternately applying and taking off the pressure I can produce the familiar effect so well known in the toy called "the bottle imps." It is this singular property which gives to cork its value as a means of closing the mouths of bottles. Its elasticity has not only a very considerable range, but it is very persistent. Thus in the better kind of corks used in bottling champagne and other effervescing wines, you are all familiar with the extent to which the corks expand the instant they escape from the bottles. I have measured this expansion, and find it to amount to an increase of volume of 75 per cent., even after the corks have been kept in a

state of compression in the bottles for ten years. If the cork be steeped in hot water, the volume continues to increase till it attains nearly three times that which it occupied in the neck of the bottle.

When cork is subjected to pressure, either in one direction, as in this lever press, or from every direction, as when immersed in water under pressure, a certain amount of permanent deformation or "permanent set" takes place very quickly. This property is common to all solid elastic substances when strained beyond their elastic limits, but with cork the limits are comparatively low. You have, no doubt, noticed in chemists' and other shops that, when a cork is too large to fit a bottle, the shopkeeper gives the cork a few sharp bites, or, if he be more refined, he uses a pair of specially-contrived pincers; in either case he squeezes the cork beyond its elastic limits, and so makes it permanently smaller. Besides the permanent set, there is a certain amount of what I venture to call sluggish elasticity—that is, cork on being released from pressure, springs back a certain amount at once, but the complete recovery takes an appreciable time.

While I have been speaking, a piece of fresh cork, loaded so as barely to float, has been inserted into the vertical glass pressure tube. I apply a slight pressure, you see the cork sinks. I release the pressure, and it rises briskly enough. I now apply a much higher pressure for a moment or two. I release it, and the cork will either not rise at all, or will do so very slowly; its volume has been permanently altered; it has taken a permanent set.

In considering the properties of most substances, our search for the cause of these properties is baffled by our imperfect powers and the feeble instruments we possess for investigating molecular structure. With cork, happily, this is not the case; an examination of its structure is easy, and perfectly explains the cause of its peculiar and valuable properties.

All plants are built up of minute cells of various forms and dimensions. Their walls or sides are composed chiefly of a substance called cellulose, frequently associated with lignine, or woody matter, and with cork, which last is a nitrogenous substance, found in many portions of plants, but is especially developed in the outer bark of exogenous trees, that is, trees belonging to an order, by far the most common in these latitudes, the stems of which grow by the addition of layers of fresh cellulose tissue outside the woody part and inside the bark. Between the bark and the wood is interposed a thin fibrous layer, which, in some trees, such as the lime, is very much developed, and supplies the bass matting with which all are familiar. The corky part of the bark, which is outside, is composed of closed cells exclusively, so built together that no connection of a tubular nature runs up and down the tree, although horizontal passages radiating towards the woody part of the tree are numerous. In the woody part of the tree, on the contrary, and in the inner bark, vertical passages or tubes exist, while a connection is kept up with the pith of the tree by means of medullary rays. In one species of tree, known as the cork oak, the corky part of the bark is very strongly developed. I project on the screen the magnified image of a horizontal section of the bark of the cork oak; you see nine or ten bands running parallel to each other: these are the layers of cellulose matter that have been deposited in successive years. I turn the specimen, and you now see the vertical section with the radiating passages clearly marked.

The difference between the arrangement of the cells or tissue forming the woody part of the tree and the bark is easily shown. I have here three metal sockets, supported over a shallow wooden tray. Into them are fitted, first, a cork cut out of the bark in a vertical direction, next, a cork cut in a radial direction, and, lastly, a piece of common yellow pine. By means of my force-pump, I apply a couple of atmospheres of hydraulic pressure. I project an image of the apparatus on the screen, and you see the water has made its way through the wood and through the cork cut in the radial direction, while the cork cut in the vertical direction is impervious.

The cork tree, a species of evergreen oak, is indigenous in Portugal and along both shores of the Mediterranean. The diagram on the wall has been painted from a sketch obligingly sent to me by

Mr. C. A. Friend, the resident engineer of the Seville Waterworks, to whom I am also indebted for this branch of a cork tree, those acorns, this axe used in getting the cork, and for a description of the habits of the tree, its cultivation, and the mode of gathering the harvest.

The cork oak attains a height of 30 to 40 feet; it is not cultivated in any way, but grows like trees in a park. The first crop is not gathered till the tree is thirty years old, the next nine or ten years later; both these crops yield inferior cork, but at the third crop, gathered when the tree is fifty years old, the bark has attained full maturity, and after that will yield the highest quality of cork every nine or ten years. In the autumn of the year, when the bark is in a fit state, that is, for small trees, from three-quarters of an inch to one inch thick, and for larger ones up to one inch and a half, a horizontal cut is made by means of a light axe like the one I hold in my hand through the bark a few inches above the ground; succeeding cuts are made at distances of about a yard, up to the branches, and then along some of the larger ones, then two or more vertical cuts, according to the size of the tree, and the bark is then cut off by inserting the wedge-shaped end of the axe-handle. In making the cuts great care is taken to avoid wounding the inner bark, upon the integrity of which the health of the tree depends; but where this precaution is taken, the gathering of the cork does not in any way injure the tree.

After stripping, the cork is immersed for about an hour in hot water, it is dressed with a kind of spokeshave, then laid out flat and weighted, in order to take out the curvature; it is then stacked in the open air, without protection of any kind, for cork does not appear to be susceptible of receiving injury from the weather.

The minute structure of the bark is very remarkable. First, I project on the screen a microscopic section of the wood of the cork tree. It is taken in a horizontal plane, and I ask you to notice the diversity of the structure, and especially the presence of large tubes or pipes. I next exhibit a section taken in the same plane of the corky portion of the bark. You see the whole substance is made up of minute many-sided cells about 1 750 of an inch in diameter, and about twice as long, the long way of the cells being disposed radially to the trunk. The walls of the cells are extremely thin, and yet they are wonderfully impervious to liquids. Looked at by reflected light, if the specimen be turned, bands of silvery light alternate with bands of comparative darkness, showing that the cells are built on end to end in regular order. The vertical section next exhibited shows a cross section of the cells looking like a minute honeycomb. In some specimens large numbers of crystals are found. These could not be distinguished from the detached elementary spindle-shaped cells, of which woody fiber is made up, were it not for the powerful means of analysis we have in polarized light. I need hardly explain to an audience in this Institution that light passed through a Nicol prism becomes polarized, that is to say, the vibrations of the luminiferous ether are all reduced to vibrations in one plane, and consequently, if a second prism be interposed and placed at right angles to the first, the light will be unable to get through; but if we introduce between the crossed Nicols a substance capable of turning the plane of vibration again, then a certain portion of the light will pass. I have now projected on the screen the feeble light emerging from the crossed Nicols. I introduce the microscopic preparation of cork cells between them, and you see the crystals glowing with many colored lights on a dark ground.

Minute though these crystals are, they are very numerous and hard, and it is partly to them that is due the extraordinary rapidity with which cork blunts the cutting instruments used in shaping it. Cork-cutters always have beside them a sharpening-stone, on which they are obliged to restore the edges of their knives after a very few cuts.

The cells of the cork are filled with gaseous matter, which is very easily extracted, and which has been analyzed for me by Mr. G. H. Ogston, and proved to be common air. I have here a glass tube in which are some pieces of cork which have been cut into slices so as to facilitate the escape of the air. I connect the tube with an exhausted receiver and project the image on the screen; you see rising from the cork bubbles of air as

numerous, but much more minute than the bubbles which rise from sparkling wines; much more minute, because the bubbles you see are expanded to seven or eight times their volume at atmospheric pressure on account of the vacuum existing in the tube. The air will continue to come off for an hour or more, and from measurements made by Mr. Ogston I find that the air occluded in the cork amounts to about 53 per cent. of its volume. The facility with which the air escapes, compared with the impermeability of cork to liquids, is very remarkable.

I throw on the screen the image of a section cut from a cork which was kept under a vacuum of about 26 inches for five days and nights; aniline dye was then injected, and yet you see that the color has not more than permeated the outermost fringe of cells—those, in fact, which had been broken open by the operation of cutting the cork. By keeping cork for a very long time in an almost perfect vacuum, and then injecting dye, a slight darkening of the general color of a section of the cork may be noticed, but is very slight indeed. How, then, does the air escape so readily when the cork is placed *in vacuo?*

The answer is, that gases possess the property of diffusion; that is, of passing through porous media of inconceivable fineness. When two gases, such as hydrogen and air, are separated by a porous medium, they immediately begin to pass into each other, and the lighter gas passes through more quickly than the heavier.

I have here a glass tube, the upper end of which is closed by a thin slice of cork, the lower end dips into a basin of water. Some hours ago the tube was filled with hydrogen, which you know is about 14½ times lighter than air; consequently, according to the law of diffusion, it will get out of the tube through the cork quicker than the air can get in by the same means, and the result must be that a partial vacuum will be formed in the tube, and a column of water will be drawn up. You see that such has been the case, and we have thus proved that the cells of cork are eminently pervious to gases. The pores in the cell-walls appear, however, to be too minute to permit the passage of liquids.

I closed the end of a glass tube 11 mm. diameter, with a disk of cork 1.75 mm. thick, cut at right angles to the axis of the tree; I placed a solution of blue litmus inside the tube, and suspended it in a weak solution of sulphuric acid. Had diffusion taken place, both liquids would have assumed a red color, but after sixteen hours no change whatever could be detected. A like inertness was exhibited when the tube was filled with a solution of copper sulphate and suspended in a weak solution of ammonia; a deep blue color would have appeared had any intermixture taken place, and the same tube is before you immersed in ammonia and filled with red litmus solution. It has been in this condition since February 28, but no diffusion has taken place. A disk of wood 6 mm. thick under the same circumstances showed, after a couple of hours, by the liquids turning blue, that diffusion was going on actively. It is this property of allowing gases to permeate while completely barring liquids that enables cork to be kept in compression under water or in contact with various liquids without the air-cells becoming water-logged, and that makes cork so admirable an article for waterproof wear, such as boot-soles and hats; for, unlike india-rubber, it allows ventilation to go on while it keeps out the wet. The cell-walls are so strong, notwithstanding their extreme thinness, that they appear, when empty, to be able to resist the atmospheric pressure, for the volume of the cork does not sensibly diminish, even when all the air has been extracted. Viewed under very high power, cross-stays or struts of fibrous matter may be distinguished traversing the cells; these, no doubt, add to the strength and resistance of the structure.

From what you have seen you will have no difficulty in arriving at the conclusion that cork consists, practically, of an aggregation of minute air-vessels, having very thin, very water-tight, and very strong walls, and hence, if compressed, we may expect the resistance to compression to rise in a manner more like the resistance of gases than the resistance of an elastic solid such as a spring. In a spring the pressure increases in proportion to the distance to which the spring is compressed, but with gases the pressure increases in a much

more rapid manner; that is, inversely as the volume which the gas is made to occupy. But from the permeability of cork to air, it is evident that, if subjected to pressure in one direction only, it will gradually part with its occluded air by effusion, that is by its passage through the porous walls of the cells in which it is contained. This fact can be readily demonstrated by the lever press which I have used; for, if the brass cylinder containing the cork be filled with soap and water and pressure be then applied, minute bubbles will be found to collect on the surface, and their formation will go on for many hours.

On the other hand, if cork be subjected to pressure from all sides, such as operates when it is immersed in water under pressure, then the cells are supported in all directions, the air in them is reduced in volume, and there is no tendency to escape in one direction more than another. An india-rubber bag, such as this, distended by air, bursts, as you see, if pressed between two surfaces; but if an india-rubber cell be placed in a glass tube and subjected to hydraulic pressure, it is merely shriveled up; the strain on its walls is actually reduced.

To take advantage of the peculiar properties of cork in mechanical applications, it is necessary to determine accurately the law of its resistance to compression, and for this purpose I instituted a series of experiments of this kind. Into a strong iron vessel of $5\frac{1}{2}$ gallons capacity I introduced a quantity of cork, and filled the interstices full of water, carefully getting out all the air. I then proceeded to pump in water, until definite pressures up to 1,000 pounds per square inch had been reached, and at every 100 pounds the weight of water pumped in was determined. In this way, after many repetitions, I obtained the decrease of volume due to any given increase of pressure. The observations have been plotted into the form of a curve, which you see on the diagram on the wall. The base-line represents a cylinder containing one cubic foot of cork divided by the vertical lines into ten parts; the black horizontal lines according to the scale on the left hand represent the pressures in pounds per square inch which were necessary to compress the cork to the corresponding volume. Thus to reduce the volume to one-half required a pressure of 250 pounds per square inch. At 1,000 pounds per square inch the volume was reduced to 44 per cent.; the yielding then became very little, showing that the solid parts of the cells had nearly come together, and this corroborates Mr. Ogston's determination that the gaseous part of cork constitutes 53 per cent. of its bulk. The engineer, in dealing with a compressible substance, requires to know not only the pressure which a given change of volume produces, but also the work which has to be expended in producing the change of volume. The work is calculated by multiplying the decrease of volume by the mean pressure per unit of area which produced it. The ordinates of the dotted curve on the diagram with the corresponding scale of foot-pounds on the right-hand side are drawn equal to the work done in compressing a cubic foot of cork to the several volumes marked on the base-line. I have not been able to find an equation to the pressure curve; it seems to be quite irregular, and hence the only way of calculating the effects of any given change of volume is to measure the ordinates of the curve constructed by actual experiment. As may be supposed, the pressures indicated by experiment are not nearly so regular and steady as corresponding experiments on a gas would be, and the actual form of the curves will depend on the quality of the cork experimented on.

The last point of importance in this inquiry relates to the permanence of elasticity in cork.

So far as preservation of elasticity during years of compression is concerned, we have the evidence of wine corks to show that a considerable range of elasticity is retained for a very long time. With respect to cork subjected to repeated compression and extension, I have very little evidence to offer beyond this, that cork which had been compressed and released in water many thousand times had not changed its molecular structure in the least, and had continued perfectly serviceable. Cork which has been kept under a pressure of three atmospheres for many weeks appears to have shrunk to from 80 to 85 per cent. of its original volume.

I will conclude this lecture by bringing

under your notice two novel applications of cork to the arts.

Before the lecture table stands a water-raising apparatus called a hydraulic ram. The structure of the machine is shown by a diagram on the wall. The ram consists of an inclined pipe, which leads the water from the reservoir into a chamber which terminates in a valve opening inwards. Branching up from the chamber is a passage leading to a valve opening outwards and communicating with a regulating vessel, which is usually filled with air, but which I prefer to fill with cork and water. Immediately beyond the inner valve is inserted a delivery pipe, which is laid to the spot to which the water has to be pumped, in this case to the fountain jet in the middle of this pan.

The action of the ram is as follows: The outer valve, which opens inward, is, in the first instance, held open, and a flow of water is allowed to take place through it down the pipe and chamber. The valve is then released, and is instantly shut by the current of water which is thus suddenly stopped, and, in consequence, delivers a blow similar to that produced by the fall of a hammer on an anvil, and just as the hammer jumps back from the anvil, so does the water recoil back to a small extent along the pipe.

During this action, first, a certain portion of water is forced by virtue of the blow through the inner valve, opening outwards, into the cork vessel, and so to the delivery pipe, and instantly afterwards the recoil causes a partial vacuum to form in the body of the ram, and permits the atmospheric pressure to open the outer valve and re-establish a rush of water as soon as the recoil has expended itself. In the little ram before you, this action, which it has taken so long to describe, is repeated 140 times in a minute.

The ram is now working. You hear the regular pulses of the valve, and you see a jet of water rising some 10 feet into the air. I throw the electric light on the water, and I ask you to notice the regularity of the flow. You can, indeed, detect the pulses of the ram in the fountain, but that is because I am only using a regulating vessel of the same capacity as that generally used for air, and you will recollect that 44 per cent. of the substance of cork is solid and inelastic. By closing a cock I can cut off the cork vessel from the ram; you see the regularity of the jet has disappeared; it now goes in leaps and bounds. This demonstrates that the elasticity of cork is competent to regulate the flow of water. When air is used for this purpose the air-vessel has to be filled, and, with most kinds of water, the supply has to be kept up while the ram is working, because water under pressure absorbs air. For this purpose a "sniff-valve" is a necessary part of all rams. It is a minute valve opening inwards, placed just below the inner valve; at each recoil a small bubble of air is drawn in and passed into the air-vessel. This "sniff-valve" is a fruitful source of trouble. Its minuteness renders it liable to get stopped up by dirt; it must not, of course, be submerged, and, if too large, it seriously affects the duty performed by the ram. The use of cork gets rid of all these difficulties, no sniff-valve is needed, the ram will work deeply submerged, and there is no fear of the cork vessel ever getting empty. The duty which even the little ram before you has done is 65 per cent., and larger ones have reached 80 per cent.

The second novel application of cork is for the purpose of storing a portion of the energy of the recoil of cannon, for the purpose of expending it afterwards in running them out.

The result of the explosion of gunpowder in a gun is to drive the shot out in one direction, and to cause the gun to recoil with equal energy the opposite way. To restrain the motion of the gun, "compressors" of various kinds are used, and in this country, for modern guns, they are generally hydraulic, that is to say, the force of recoil is expended in causing the gun to mount an inclined plane, and, at the same time, in driving a piston into a cylinder full of water, the latter being allowed to squeeze past the piston through apertures, the areas of which are either fixed or capable of being automatically varied as the gun recedes; or else the water is driven out of the cylinder through loaded valves. As a rule, the gun is moved out again into its firing position by its weight causing it to run down the inclined plane, up which it had previously recoiled. For naval pur-

poses, however, this plan is inconvenient, because the gun will not run out to windward if the vessel is heeling over, on account of the inclined plane becoming more horizontal, or even inclined in the reverse direction, and should the ship take a permanent list, from a compartment getting full of water, the inconvenience might be very considerable.

In land service guns, when mounted in barbette, the rising of the gun exposes it and the loading detachment more to the enemy's fire, and in both cases, when placed in ports or embrasures, the ports must be higher than if the gun recoiled horizontally, and will therefore offer a better mark to the enemy's fire, especially that of machine guns, while the sudden rise of the gun in recoiling imposes a severe downward pressure on the deck or on the platform.

To obviate these disadvantages I have contrived the gun-carriage a model of which is before you on the table, and a diagram of which on the wall illustrates the internal construction. The gun is mounted on a carriage composed of two hydraulic cylinders, united so as to form one piece. The carriage slides on a pair of hollow ways, and also on to a pair of fixed rams, the rear ends of which are attached to the piece forming the rear of the mounting. There are water passages down the axes of the rams, and these communicate through an automatic recoil-valve, opening from the cylinders, with the two hollow slides. There is a second communication between the cylinders and slides by means of a cock, which can be opened or shut at pleasure. The hollow slides are packed full of cork and water, the latter also completely filling the cylinders, rams, and various connecting passages.

By means of a small force-pump enough water can be injected to give the cork so much initial compression as will suffice to run the gun out when the slides are inclined under any angle which may be found convenient.

When the gun is fired, the cylinders are driven on to the rams, and the water in the cylinders is forced through the hollow rams into the cork and water vessels formed by the slides, and the cork is compressed still farther. When the recoil is over, the automatic recoil-valve closes, and the gun remains in its rearward position ready for loading.

As soon as loaded, the running-out cock is opened, the expansion of the cork drives the water from around it into the cylinders, and so forces the gun out.

If it be desired to let the gun run out automatically immediately after recoil, it is only necessary to leave the running-out cock open, and then the water forced among the cork by recoil returns instantly to the cylinders, and runs the gun out quicker than the eye can follow the motion.

I will now load the model and fire a shot into this strong steel cylinder, at the bottom of which is a thick layer of soft wood. I will close the running-out valve, so that the gun shall remain in the recoiled position. Sir Frederick Abel has kindly arranged some of his electric fuses specially to fit this minute ordnance, and I can fire the gun by means of a small electro-magnetic battery. The gun has now recoiled, and remains in its rear position. I load again, open the running-out cock, the gun runs out, and I fire without closing the cock. You see the gun has recoiled and run out instantly again.

The arrangement I have adopted may be made by using air instead of cork, but air is a troublesome substance to deal with; it leaks out very easily, and without showing any signs of having done so, which might readily lead to serious consequences. A special pump is required to make up loss by leakage.

The merit of cork is its extreme simplicity and trustworthiness. By mixing a certain proportion of glycerine with the water it will not freeze in any ordinary cold weather.

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A Magnesium Torch.—At a recent meeting of the Pharmaceutical Society, a cylinder of magnesium 10 in. long was shown by Messrs. Hopkins and Williams. When produced in a dense and massive form, such as this, there is less tendency to rapid combustion when burning. Magnesium torches are now used in Germany for the illumination of mines. The cost of the metal is now about 30s. per pound.

# WATER PURIFICATION—ITS BIOLOGICAL AND CHEMICAL BASIS.

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## I.

Although the purification of water has received much attention during the past thirty years, it is only now that the complexity of this subject is beginning to be realized.

The earliest attempts to purify water had for their object simply the clarification of the liquid, *i.e.*, the removal of suspended particles visible to the naked eye.

In this purification there was no endeavor to remove dissolved matters, and suspended particles invisible to the naked eye were not then thought of. It cannot be doubted that, in most cases, this primitive conception of water-purification has still been retained, the sole idea of the operator being to produce a liquid clear and sparkling to the eye.

The advances of chemical science caused attention to be paid to the matters present in water in the state of solution, and more particularly to those of an organic nature. In the first place, it was supposed that organic substances were capable of imparting alteration and decay to other organic substances with which they were placed in contact; this being the theory of fermentation advanced by Liebig. Thus Liebig conceived that ordinary alcoholic fermentation was brought about not by the living and growing yeast, but by the dead yeast-cells undergoing decomposition. As long as this theory was the accepted doctrine of the day, it was not surprising to find chemists attaching great importance to the organic matter in water which analysis revealed, and which was known to have been derived from decomposing vegetable and animal substances with which the water had been in contact. It was naturally supposed that such decomposing organic matter in water would tend to set up putrefactive and other injurious changes in the digestive organs through which it passed.

The theory, or rather dogma, of fermentation enunciated by Liebig, was soon broken down by the classical researches of Pasteur, by whom it was shown that the processes of fermentation and putrefaction were due not to decomposing organic matter, but to living organisms, and that living organisms were also certainly the cause of some and probably of all zymotic diseases. Under these circumstances, the organic matter present in water came to be viewed in a different light, and instead of being regarded as in itself unwholesome, it could now only be taken as affording more or less evidence of the possible presence of organisms endowed with virulent properties. As it was further established beyond doubt, by bitter practical experience, that certain zymotic diseases—notably typhoid fever and cholera—could be communicated by means of sewage-polluted water, the chemical examination of water was prosecuted with a view of ascertaining the presence or absence of such contamination by means of the organic matter which the water was found to contain. Through refinement in the processes of chemical analysis it has, moreover, been rendered possible to discriminate with a very considerable degree of certainty between organic matter of vegetable, and that of animal origin. The detection of animal matter in water was not supposed to carry with it *ipso facto* the certainty of danger, but in the absence of any precise knowledge concerning those organisms which produce zymotic disease, the presence of such animal matter obviously indicated the possibility of danger.

It is thus seen that in this second stage of progressive knowledge, the purity of water was at first gauged merely from a chemical point of view, and that afterwards, through the researches of Pasteur and others, it came to be understood that chemical purity was really of less importance than biological purity; but owing to the absence of any satisfactory means

of examining waters biologically, the chemical standard was the only one by which they could be judged.

Under these circumstances, it was natural that means should be devised to render water as chemically pure as possible, on the assumption that the conditions which tended to improve the chemical quality would similarly affect it biologically. This is essentially the period of the late Rivers Pollution Commission, in which so many methods of water and sewage purification are fully discussed by the light of chemical analysis. In these discussions, the importance of the biological side of the subject is fully recognized, but owing to the absence of any reliable methods at that time, the examination was not pursued in this direction.

It is to the vastly improved methods of biological examination that the only great step which has been made in the knowledge of the purification of water since the researches of the last Commission is to be attributed. These methods of biological examination, which are largely due to the genius of Dr. Robert Koch, of Berlin, enable the merely chemical investigation of the subject of water purification to be supplemented in a manner that was never possible before.

This method of examination is based upon principles of such exquisite simplicity, that a very brief description will suffice to render it intelligible.

The microscopic living particles known as "micro-organisms," or "mycrophytes," which it is the object of a biological examination to study, possess such an astonishing power of rapid multiplication when they are placed in a medium fitted for their growth, that within a very short period of time it becomes impossible to form an opinion as to the number of original organisms from which the vast population is descended.

Thus, if such micro-organisms be distributed throughout a medium suitable for their multiplication, and if each individual organism be then immediately deprived of the possibility of movement, the number of colonies arising from the multiplication of these isolated individuals indicates the number of organisms introduced, whilst, by the nature of the colonies formed, the kinds of organisms of which the original importation consisted may be ascertained.

If the conditions here indicated can be complied with, it is obvious that all the means are at hand for determining the effect of any method of water-treatment upon these lowest forms of organic life. This imprisonment, so to speak, of each individual and its subsequent progeny, which is thus the key to the whole problem, can be readily effected by adding to a nutritive liquid, such as extract of meat, a sufficient quantity of gelatine to render the whole solid at the ordinary temperature. The process consists, in short, in taking a known volume, *e.g.*, 1 cubic centimeter of water, and mixing it with a quantity of such nutritive gelatine, that has been melted at the temperature of the hand, and then pouring the mixture upon a glass plate on which it sets in the course of a few minutes to a solid mass. The plate is placed under a glass cover, so as to protect it from dust, and is kept at a temperature of about 20° to 25° Centigrade. In the course of from three to five days the colonies, each originating from a single organism, attain such dimensions that they may be recognized and counted with the naked eye or by means of a microscope of low magnifying power.

It is thus evident that the purification of water must now be regarded from two distinct points of view—the chemical and the biological—and that whereas formerly the biological side was almost wholly of a speculative character, it is now nearly, if not quite as tangible as the chemical side. Thus, perhaps a concrete example will most clearly illustrate how the purification of water should be regarded. Supposing that water, derived from a source which is altogether unimpeachable as regards contamination with animal matters, is yet so highly impregnated with vegetable constituents as to be objectionable for drinking purposes, the question will arise how this water may be treated so as to render it suitable for domestic supply. In a case of this kind it is obvious that chemical purification will be of paramount importance, whilst the removal of organic life from the water will be of less pressing consequence. On the other hand, if water which is known to have received sewage matters is to be supplied for dietetic use, and if this water, as is so

often the case, is not objectionable on account of the absolute quantity of organic matter which it contains, but only because of the suspicious origin of a part of this organic matter, then it is evident that in the purification of such water the point to be taken primarily into consideration, is how the organic life it contains can be reduced to a minimum.

In estimating the value of such processes of purification, it has hitherto been customary to assume that those processes which effect the greatest chemical improvement in water may also be safely considered to be biologically the most excellent; and conversely, that those processes which effect little or no reduction in the proportion of organic impurity are not calculated to be of any service in removing organized matters.

In the experiments which the author has for some time been conducting on the removal of micro-organisms from water, the first results of which he communicated to the Royal Society in May, 1885, he has found that this assumed law, or at least its converse, is very far from being correct. Thus the author discovered that some materials were capable of filtering out all the organisms in water without appreciably altering its chemical composition.

The author's inquiry into the chemical and biological purification of water may be conveniently considered under four heads:

1. Purification by filtration.
2. Purification by agitation with solid particles.
3. Purification by precipitation.
4. Purification by natural agencies.

### I. Purification by Filtration.

Until the method of water examination by gelatine-culture was devised, there were no available means by which the relative efficiency, for the removal of micro-organisms, of different filtering materials could be estimated on a quantitative basis.

The author has submitted to examination, as regards their efficiency in this respect, a number of filtering materials, employing in all cases equal thicknesses of the various substances, which were also prepared in the same state of division. The filtering stratum was constructed exactly 6 inches in depth, and the filtering material was, with a few exceptions, made to pass through a sieve of 40 meshes to the linear inch. The results obtained in these experiments were:

| Filtering Material. | Efficiency. | Organisms per Cubic Centimeter. | | Reduction per cent. | Approximate rate of filtration per square foot per hour. |
|---|---|---|---|---|---|
| | | Unfiltered Water. | Filtered Water. | | |
| | | | | | Gallons. |
| Ferruginous greensand (from Redhill, Surrey) | Initial | 80 | — | 100.0 | — |
| | After thirteen days' action | 8,000 | 1,000 | 88.0 | 0.73 |
| | After one month's action. | 1,280 | 780 | 39.0 | 1.14 |
| Animal-charcoal | Initial | Too numerous to count. | — | 100.0 | — |
| | After twelve days' action. | 2,800 | — | 100.0 | 0.46 |
| | After one month's action. | 1,280 | 7,000 | Increase 447.0 | 0.86 |
| Iron sponge | Initial | 80 | — | 100.0 | — |
| | After twelve days' action | 2,800 | — | 100.0 | 0.40 |
| | After one month's action. | 1,280 | 2 | 99.8 | 0.45 |
| Brick-dust (pulverized red brick) | Initial | 3,000 | 730 | 76.0 | — |
| | After five weeks' action. | 6,000 | 400 | 93.0 | 0.48 |
| Coke | Initial | 3,000 | — | 100.0 | — |
| | After five weeks' action. | 6,000 | 90 | 98.5 | 0.50 |

The author has made further experiments on the efficiency of coke as a filtering material. In these experiments the filters employed were of similar construction to those already described, but an aqueous extract of garden-soil was employed instead of urine-water.

Two similar filters (*a*) and (*b*) were submitted to examination, under conditions as similar as possible:

INITIAL EFFICIENCY (SECOND DAY).

Per cubic centimeter.

Unfiltered water.....26,000 organisms.
Filter (*a*)..... 0 "
Filter (*b*)..... 0 "

Reduction (*a*)=100 per cent.
" (*b*)=100 "

Per square foot per hour.

Approximate rate of filtration (*a*)=0.89 gallon.
" " " (*b*)=0.67 "

AFTER THREE WEEKS' ACTION (TWENTY-FIRST DAY).

Per cubic centimeter.

Unfiltered water.....2,230 organisms.
Filter (*a*)..... 339 "
Filter (*b*)..... 219 "

Reduction (*a*)=85 per cent.
" (*b*)=90 "

Per square foot per hour.

Approximate rate of filtration (*a*)=1.32 gallon.
" " " (*b*)=1.03 "

On comparing these latter experiments with those previously obtained, it will be seen that although the initial efficiency was in both cases the same, the greater rate of filtration which prevailed in the latter experiments caused the efficiency to deteriorate more rapidly, the filter (*a*), which was the most rapid, breaking down to a greater extent than the less rapid filter (*b*).

The unfiltered and filtered waters, respectively, were also submitted to chemical examination, at the time that the filters were exerting their greatest efficiency in the removal of micro organisms; the results are given in the following table, together with those obtained by the filtration of the same water through fine vegetable-charcoal, and through a mixture of fine and coarse vegetable-charcoal, respectively:

RESULTS OF ANALYSIS EXPRESSED IN PARTS PER 100,000.

| | Unfiltered Water. | Water from Fine Coke | | Water from Fine Wood Charcoal. | Water from Coarse and Fine Wood Charcoal. |
|---|---|---|---|---|---|
| | | A. | B. | | |
| Total solids | 24.80 | 24.60 | 25.00 | 24.68 | 24.64 |
| Organic carbon | 0.144 | 0.118 | 0.107 | 0.090 | 0.098 |
| Organic nitrogen | 0.050 | 0.040 | 0.038 | 0.024 | 0.031 |
| Ammonia | 0 | 0 | 0 | 0 | 0 |
| Nitrogen as nitrates and nitrites | 0.190 | 0.209 | 0.202 | 0.221 | 0.217 |
| Total combined nitrogen | 0.240 | 0.249 | 0.240 | 0.245 | 0.248 |
| Chlorine | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 |
| Temporary hardness | 11.3 | 11.3 | 11.3 | 12.5 | 12.3 |
| Permanent hardness | 5.6 | 5.6 | 5.6 | 4.6 | 4.6 |
| Total hardness | 16.9 | 16.9 | 16.9 | 17.1 | 16.9 |

These results show that filtration through coke exerts but an insignificant chemical action, even when the purification from a biological point of view is complete.

*Vegetable-Charcoal.*—The very favorable results obtained with coke led the author to investigate the filtering power of the still more porous vegetable or wood charcoal. This material was also

passed through the same sieve, and employed in filters of similar construction. In the first experiment urine-water was used, with the following results:

INITIAL EFFICIENCY (SECOND DAY).

| | Organisms per Cubic Centimeter. |
|---|---|
| Unfiltered water | 9,700 |
| Water filtered through fine charcoal | 0 |

Reduction=100 per cent.

Later experiments were made with an aqueous extract of soil, the following results being obtained:

INITIAL EFFICIENCY (SECOND DAY),

| | Organisms per cubic centimeter. |
|---|---|
| Unfiltered water | 2,898 |
| After filtration through fine wood-charcoal | 0 |

Reduction=100 per cent.

Approximate rate of filtration=0.22 gallon per square foot per hour.

AFTER ONE MONTH'S ACTION (TWENTY-NINTH DAY).

| | Organisms per cubic centimeter. |
|---|---|
| Unfiltered water | 2,230 |
| After filtration through wood charcoal | 107 |

Reduction=95 per cent.

Approximate rate of filtration=0·22 gallon per square foot per hour.

It is thus seen that the efficiency of the fine charcoal at the end of one month is less than that of the coke with the slow rate of filtration, but greater than that of the more rapid coke filters at the end of three weeks, the rate of filtration in the case of the charcoal being markedly less than in any of the coke experiments.

In order to obtain a more rapid charcoal filter, an intimate mixture was made of equal parts of coarse and of fine charcoal, the former having passed through a sieve of 9 wires by 30 wires to the square inch, and the latter through one of 40 meshes to the linear inch, and this was introduced into a glass tube, so as to form a stratum of filtering material 6 inches in depth. With this filter the following results were obtained:

INITIAL EFFICIENCY (SECOND DAY).

| | Organisms per cubic centimeter. |
|---|---|
| Unfiltered water | 26,000 |
| Filtered through coarse and fine charcoal | 0 |

Reduction=100 per cent.

Approximate rate of filtration=0·26 gallon per square foot per hour.

AFTER THREE WEEKS' ACTION (TWENTY-FIRST DAY).

| | Organisms per cubic centimeter. |
|---|---|
| Unfiltered water | 2,230 |
| Filtered through coarse and fine charcoal. | 506 |

Reduction=77 per cent.

Approximate rate of filtration=0·59 gallon per square foot per hour.

Thus with wood-charcoal, when the rate of filtration approaches that through coke, the improvement, from a biological point of view, is markedly less. The effect which this material has upon the chemical composition of the water, as exhibited in the above table, is greater than that of coke, but is also not very considerable.

It has generally been supposed that most filtering materials offer little or no barrier to micro-organisms, and that the latter are capable of passing without sensible obstruction through the pores of filters containing pulverized materials. These experiments, however, show that it is extremely simple to construct filters which shall possess the power of removing micro-organisms, in the first instance at least. This power is, moreover, possessed by substances which exercise scarcely any chemical action on the organic matter present in the water, *e.g.*, coke, vegetable-charcoal, and biscuit-porcelain, as well as by those which reduce both the organic and the mineral ingredients of the water to a very marked extent, like animal-charcoal and iron.

Especially noticeable is the case of vegetable-carbon, whether in the form of charcoal or of coke; this material has been generally regarded as of but little value for water purification, owing to its chemical inactivity, but as biological filters these substances occupy a high place, and owing to their cheapness and the facility with which they may be renewed, and profitably disposed of as fuel, they are, in the author's opinion, destined to be of great service in the purification of water.

These materials, coke and vegetable-charcoal, are also especially well fitted for use in breweries and distilleries, where it is so necessary to have a water which, though perfectly free from organic life, is at the same time free from antiseptic substances, such as iron, which militate against fermentation. Coke has already been used, at the author's suggestion, with marked success.

These experiments, however, show most distinctly the necessity of frequent renewal, even in the case of the best filtering materials, and this is a point which, unfortunately, is too often lost sight of.

Lastly, they furnish abundant confirmation of the principle which has been long known to waterworks engineers, viz, that which is gained in rapidity, is lost in efficiency, and *vice versa.*

### II. Purification by Agitation with Sold Particles.

This method of water purification has recently been brought prominently before the public by Mr. W. Anderson, M. Inst. C.E., who has patented a process for agitating water with scrap-iron in a revolving cylinder. Some of the results obtained by this method have been brought before the Institution of Civil Engineers by Mr. W. Anderson and Mr. G. H. Ogston, Assoc. Inst. C.E. In this process, however, the purification is probably due almost entirely to chemical action, inasmuch as a portion of the iron passes into solution, and is subsequently precipitated in a settling-tank by contact with the air. This process is employed on a large scale at the Antwerp Waterworks, where it has superseded filtration through spongy iron; and on a large experimental scale it may be seen in operation at the Lee Bridge works of the East London Waterworks Company.

The author has not himself examined this particular method of purification, but he has made a number of experiments in order to ascertain whether, and to what extent, the organized matters in water may be removed by agitation with finely-divided solid particles of various kinds.

It appeared probable, from the results of the filtration-experiments already described, that organized substances might be largely removed by mere contact with finely-divided matter. A series of experiments was consequently undertaken with a view to ascertain to what extent this was the case, and in some instances the reduction was found to be much greater than could have reasonably been anticipated.

In these experiments water containing micro-organisms was shaken up for a definite length of time with a given quantity of the finely-divided matter, which was used in the same state of subdivision as in the filters already described. The water was then allowed to subside, and the clarified water submitted to examination, as soon as possible after complete subsidence had taken place, as it appeared probable that if the organisms were simply carried to the bottom by the subsiding particles without suffering any injury, they would rapidly again become distributed through the upper layers of water by multiplication. This supposition has been amply verified by experiment.

*Agitation with Spongy Iron.*—The water was shaken with one-tenth of its weight of this material for fifteen minutes. The water was allowed to subside for half-an-hour before examination.

| | Organisms per cubic centimeter. |
|---|---|
| Untreated water contained | 609 |
| After fifteen minutes' agitation | 63 |

Reduction=90 per cent.

On another occasion the water of the Thames, at Hampton, was shaken with spongy iron for fifteen minutes, with the following results:

| | Organisms per cubic centimeter. |
|---|---|
| Thames water | 155 |
| After fiteen minutes' agitation | 10 |

Reduction=93 per cent.

*Agitation with Chalk.*—Urine-water was shaken for fifteen minutes with one-fiftieth of its weight of chalk, and then allowed to subside for five hours:

| | Organisms per cubic centimeter. |
|---|---|
| Untreated water | 8,000 |
| After agitation | 270 |

Reduction=97 per cent.

*Agitation with Animal-Charcoal.*—Urine-water was shaken with one-fiftieth of its weight of animal-charcoal for fifteen minutes, and then allowed to subside for nearly five hours:

| | Organisms per cubic centimeter. |
|---|---|
| Untreated water | 8,000 |
| After agitation | 60 |

Reduction=99 per cent.

*Agitation with Vegetable-Charcoal.*—Water containing soil-extract was shaken with one-fiftieth of its weight of ordinary wood-charcoal for fifteen minutes, and was then allowed to subside for twenty-seven hours:

| | Organisms per cubic centimeter. |
|---|---|
| Untreated water | 3,000 |
| After agitation | 120 |

Reduction=96 per cent.

*Agitation with Coke.*—Urine-water was shaken with one-fiftieth of its weight of fine coke for fifteen minutes, and then allowed to subside for forty-eighty hours:

Untreated water.....Too numerous to be
After agitation with coke..None. [counted.
Reduction=100 per cent.

Further experiments made with water containing soil-extract have shown that this process of purification is unreliable, owing apparently to the numerous conditions which are necessary for its success. In some cases the number of organisms in the clear liquid was greatly increased. This being doubtless due to a re-ascension and multiplication of those which were at first carried down. Thus in one series of experiments the following results were obtained:

| | Organisms per cubic centimeter. |
|---|---|
| Untreated water | 3,000 |
| After agitation with coke and twenty-six hours' subsidence | 20,000 |

Further experiments of a similar nature were made, but less time (only five hours) was allowed for subsidence:

| | Organisms per cubic centimeter. |
|---|---|
| Untreated water | 655 |
| After agitation with coke and five hours' subsidence | 28 |

Reduction=96 per cent.

Thus, although a most remarkable purification may be accomplished by this simple process of agitation with the various substances specified, yet, owing to the uncertainty of its success, its efficiency cannot at present be relied on.

Water was also agitated with several other substances, such as china clay, brickdust, plaster of Paris, oxide of manganese, &c.; all of these, however, yielded unsatisfactory results.

The conclusion to be drawn from these experiments is that very porous substances like coke, animal and vegetable charcoal, are highly efficient in removing organized matter from water when the latter is exposed to their contact in agitation.

The removal of micro-organisms through the surface-attraction of suspended particles naturally leads to a consideration of what takes place when the suspended particles are generated in the water itself by precipitation.

### III. Purification of Water by Precipitation.

As by far the most common and most important method of water purification dependent upon precipitation is the well-known Dr. Clark's process, the effect of this on organized matters was made the subject of special study. With this view the author has examined the process both in the laboratory as well as on the large scale as practiced by manufacturers and by water companies.

*Laboratory Experiments.*—For testing the efficiency of the process on the laboratory scale, three stoppered Winchester quart bottles were taken, and to each were added two liters of ordinary London (Thames) water, to which a convenient proportion of organisms had been imparted by the addition of urine water. To two of these bottles, 100 cubic centimeters of clear lime-water were added, this being calculated to remove 11.6 parts of carbonate of lime per 100,000 parts of the water. Each of these bottles was violently shaken, and the contents were then allowed to subside for eighteen hours. The bottle to which no lime-water had been added was tested without disturbing the precipitate, as was also the third bottle which had been left at rest in the same place as the other two. These tests showed the following numbers of organisms to be present in the water before and after treatment:

| | Organisms per cubic centimeter. |
|---|---|
| Untreated water | 85 |
| After eighteen hours' rest | 1,922 |
| Water after treatment by Clark's Process and eighteen hours' subsidence. | 42 |

Reduction on original=51 per cent.

In order to appreciate the value of the treatment by Dr. Clark's process, it is necessary that the treated waters should be compared not only with the original water, but also with the untreated water after eighteen hours' rest; for the latter obviously indicates what the condition of the water would have been at the time of examination, if no lime-water had been added. It appeared probable that, after the subsidence of the carbonate-of-lime precipitate had taken place, the organisms which had been carried down by the latter would again become distributed throughout the upper layers of the water. In order to ascertain whether this was the case or not, the same waters which had remained stoppered up and at rest, were again examined after the lapse of ten days. It was then found that the untreated as well as the softened waters contained immense numbers of organisms in their upper layers.

In another series of experiments car-

ried out under the same conditions, excepting that twenty-one instead of eighteen hours were allowed for the subsidence of the carbonate of lime, a reduction in the number of organisms amounting to 41 per cent. was obtained.

*Experiments on an Industrial Scale.*—It appeared to be of great interest to ascertain what results could be obtained by Dr. Clark's process on the large scale. For this purpose the process of softening as practiced at the Colne Valley Waterworks at Bushey, near Watford, was investigated, as well as the new modification of Dr. Clark's process, devised by Messrs. Gaillet and Huet, which was lately in operation at Mr. Duncan's Sugar Refinery, Clyde Wharf, Victoria Dock. The author is indebted to Mr. Verini, of the Colne Valley Waterworks, as well as to Mr. Duncan and Mr. Newlands, for their kindness in permitting him to carry out these experiments.

At the Colne Valley Waterworks, the hard water (see analyses given below) obtained from a deep well sunk into the chalk, is mixed with the requisite proportion of clear lime-water, and then allowed to settle in open tanks. The subsidence is so rapid that under favorable circumstances the upper layers of water are, after three hours' time, fit for distribution. On the occasion of the author's visit, however, boring operations were being carried on, and the water was in consequence milky, and the necessary subsidence after softening had to be increased to two days.

A perfectly representative sample of the water before softening could unfortunately not be obtained, and the number of organisms found in the untreated water is probably in excess of that which was present in the unsoftened water. The following results were obtained:

| | Organisms per cubic centimeter. |
|---|---|
| Unsoftened water | 322 |
| Water after softening and two days' subsidence (from main) | 4 |

Reduction=99 per cent.

In Gaillet and Huet's process as carried out at Mr. Duncan's, the water from an artesian well, sunk into the chalk below the London clay, is mixed with a suitable proportion of lime-water and caustic soda, the mixture being then made to pass upwards through a tower provided with oblique diaphragms, which accelerate the precipitation of the carbonate of lime. The passage through this tower occupies a period of about two hours. Samples of the water before and after treatment were examined, with the following results:

| | Organisms per cubic centimeter. |
|---|---|
| Well water from tanks | 182 |
| Softened water | 4 |

Reduction=98 per cent.

These results, and especially those obtained on the industrial scale, conclusively prove that Clark's process is a most valuable agent for purifying water biologically, and the value of the process from a chemical point of view is illustrated by the following analyses:

Parts per 100,000.

| | Total Solids. | Organic Carbon | Organic Nitr'gen | Hardness. |
|---|---|---|---|---|
| Caterham water-supply before softening | 27.68 | 0.028 | 0 009 | 21.2 |
| After softening by Dr. Clark's process | 8.80 | 0.015 | 0.003 | 4.4 |

Gaillet and Huet's Process.

| | Well at Victoria Dock. | Clyde Wharf, Ditto after Softening. |
|---|---|---|
| Total solids | 58.76 | 44.20 |
| Organic carbon | 0.111 | 0.084 |
| Organic nitrogen | 0.017 | 0.016 |
| Ammonia | 0.050 | 0.060 |
| Nitrogen as nitrates and nitrites | 0 | 0 |
| Chlorine | 16.7 | 17.3 |
| Hardness (Temporary | 19.8 | 2.4 |
| Hardness (Permanent | 8.0 | 6.0 |
| Hardness (Total | 27.8 | 8.4 |
| Sulphuric acid | 3.96 | 4.01 |
| Silica | 1.44 | 0.69 |
| Alumina and oxide of iron | 0.22 | 0.14 |
| Lime | 12.57 | 5.96 |
| Magnesia | 2.82 | 0.57 |
| Potash | 0.93 | 1.06 |
| Soda | 13.13 | 15.76 |
| Carbonate of soda | 0 | 2.0 |
| Carbonate of lime | 21.32 | 5 39 |
| Carbonate of magnesia | 1.43 | 1.20 |
| Suspended matter: | | |
| Mineral | 0.22 | turbid. |
| Organic | 0.10 | |
| Total | 0.32 | |

On comparing the reduction of the organic matter, as indicated by chemical analysis, with the diminution in the number of micro-organisms revealed by the biological examination, it will be seen that the biological efficiency of Dr. Clark's process is markedly superior to its power as a chemical purifier. This is obviously a matter of great importance, as it shows the value of methods of precipitation in removing micro-organisms; it must,

however, be borne in mind that the particular precipitation process referred to above, is carried out with the greatest care and cleanliness, and it is a rule, to which there is no exception, that satisfactory results, as regards the removal of micro-organisms, can only be obtained when the most scrupulous care and continuous attention are given to the matter, and failure will inevitably result when such processes are not under proper supervision.

IV. Purification by Natural Agencies.

It is a matter of common knowledge that of natural waters the purest, as regards organic matter, are those which have undergone prolonged filtration through porous strata. Such waters obtained from deep wells and deep-seated springs often contain the merest trace of organic matter, which is only discoverable and capable of being quantitatively determined by the most refined analytical methods. It has also been shown by Pasteur that many of these waters are entirely destitute of organic life, or are in other words sterile.

Of a number of waters of this kind, the author has only met with isolated samples in which absolutely no organic life was revealed by cultivation with the gelatine mixture, although many have closely approached this ideal state of things. It must, however, be remembered that the collection of natural waters of this kind in a sterile condition is fraught with great difficulty, inasmuch as the places where such waters issue are almost invariably surrounded by conditions which favor the communication of organized matters to the water. Thus the damp, earthy surfaces with which the issuing water comes in contact forms a favorable seat for the development of many growths. It is probably in consequence of such contact at the surface that subterranean waters, like that of the Kent Company, are found to contain their complement, a small one only, it is true, of organic life capable of growth and multiplication in the gelatine-peptone medium. Thus the water collected direct from the Kent Company's well at Deptford contained

| | Organisms per cubic centimeter. |
|---|---|
| June 4th, 1885 (temperature 12°.4 C.)... | 6 |
| Oct 29th, " ( " 12°.0 C.)... | 6 |
| Nov. 25th, " ( " 11°.7 C.)... | 8 |

Again, the water from a spring in the Upper Greensand near Reigate contained

| | Organisms per cubic centimeter. |
|---|---|
| June 5th, 1885..... | 8 |
| And water from a deep well in the chalk at Sudbury, March 16th, 1886, contained..... | 25 |

It has often been urged as an objection to the bacteriological examination of water, that such an examination fails to distinguish between organisms which are dangerous and those which are harmless. This is, however, not the case, for there are several pathogenic or disease-producing organisms which may be readily discovered; indeed, in the case of cholera in India, this has already been done by Dr. Koch, who found the "Comma Bacillus" in a water-tank which was being used by persons suffering from cholera. The organisms of several other diseases, of which splenic fever "Bacillus anthracis" may be specially mentioned, are also capable of identification. It is only a matter of time and further investigation that other diseases shall become similarly recognisable, inasmuch as every day more precise knowledge of these forms is being acquired. The energy and enthusiasm with which this branch of study is being prosecuted is nowhere more apparent than in the Hygienic Institute of Berlin, which is directed by Dr. Koch under the auspices of the German Government. This institute has as much space and accommodation devoted to the interests of bacteriology alone as, in a government institution in this country, would be accorded to nearly all the sciences put together.

In the application of the gelatine process to the examination of potable water, the author points out that an opinion as to the biological purity of the water should be based not only upon the aggregate number of organisms found, but also upon the number of different varieties which the cultivation reveals. A water containing only one or two varieties is, *cæteris paribus*, to be preferred to one in which there are many varieties, as in the latter case it is evident that the water has been subject to numerous sources of contamination, and that it has not been exposed to influences inimical to the life of a number of different classes of micro-organisms. In his experiments on the artificial purification of water, he

has always found that it is more difficult to remove some classes of organisms than others. The following case illustrates this point in a most striking manner. In the experiments on filtration through vegetable-charcoal it has been already seen that the

| | Organisms per cubic centimeter. |
|---|---|
| Unfiltered water contained..... | 2,230 |
| Filtered " " ..... | 506 |

Reduction=77 per cent.

If, however, only those organisms which cause liquefaction of the gelatine be taken into consideration, it is found that

| | Organisms (liquid) per cubic centimeter. |
|---|---|
| Unfiltered water contained..... | 785 |
| Filtered " " ..... | 1 |

Reduction=99.87 per cent.

*Gelatine Process applied to London Waters.*—For more than a year past the author has made periodical examinations by this process of all the waters supplied to the metropolis, and the results obtained since September last have been officially furnished to the Local Government Board.

These examinations are of peculiar interest, when they are studied side by side with the results of similar examinations made of the river waters from which the metropolitan supply is mainly derived. It is, of course, impossible to obtain perfectly representative samples of the water before and after treatment by the companies, but the plan adopted has been to collect samples of the river-water as it passes the companies' intakes on the same day as that on which the samples of the water actually supplied to the consumer are collected. In this manner the samples, taken over a considerable period of time, will be representative of the average quality of the river-water on the one hand, and of the actual supply on the other. A mere glance at the results of these observations, which are embodied in the following table, will distinctly show the striking improvement, as regards the number of micro-organisms, which the river-waters undergo in passing through the companies' works. During the last four months of 1885, the average reduction in the number of micro-organisms effected by the treatment of the companies was as follows:

| 1885. | Thames. | Lee (East London Co.) |
|---|---|---|
| September | 97.8 per cent. | — |
| October. | 96.5 " | — |
| November | 98.9 " | 98.5 per cent. |
| December. | 98.5 " | 88.8 " |

These regular periodical examinations have already yielded some exceedingly important results.

Thus for the first time a definite conception has been obtained of the effect of sand-filtration upon these lower forms of life. Hitherto those who were acquainted with the size of these minute microscopic organisms on the one hand, and with the dimensions of the pores in a sand-filter on the other, have believed that little or no barrier could be offered to these organisms by the comparatively spacious pores of the filter, and even the strongest advocate of sand-filtration could not have reasonably anticipated that mere filtration through a few feet of this material could effect the remarkable reduction in the number of micro-organisms to which the above table bears witness.

It is most remarkable, perhaps, that these highly satisfactory results have been obtained without any knowledge on the part of those who construct these filters, as to the conditions necessary for the attainment of such results. In the construction of filter-beds, waterworks engineers have certainly never been guided by an acquaintance with the habits of micro-organisms, and yet by carefully improving their methods, so as to secure the removal of visible suspended matter, they have hardly less successfully, although unconsciously, attracted the invisible particles, and reduced them to an extent which is surprising.

The table, however, also shows that, great as has been the intuitive wisdom of the engineers, there is still much to be learnt in the purification of water from this new point of view. A glance at the table shows that there is a certain uniformity in the position which the various companies occupy as regards freedom from micro-organisms, and on referring to the statistics of the various companies published in Sir Francis Bolton's manual of the "London Water Supply," it is found that there is an unmistakable relationship between this position of each company and certain factors in the mode of working, which might be anticipated from theoretical considerations.

The factors which, in the author's opinion, are more especially calculated to influence the number of micro-organisms present in the distributed water are the following:

1. Storage capacity for unfiltered water.
2. Thickness of fine sand through which filtration is carried on.
3. Rate of filtration.
4. Renewal of filter-beds.

1. *Influence of Storage Capacity for Unfiltered Water.*—The influence which this factor may exercise upon the organized matter in water is manifold. In the first place, through greater storage-capacity, the necessity of drawing the worst water from the river is avoided, a matter which, in the case of a river like the Thames, which is liable to frequent floods, is of great importance. During the period of storage, subsidence takes place, the water becoming poorer in suspended particles of all kinds. Again, in these storage-reservoirs a process of starvation may go on, for the organisms present in the impounded water find themselves imprisoned with a limited amount of sustenance, which they rapidly exhaust, and then perish in large numbers, falling to the bottom. This phenomenon is sufficiently familiar to all who have made the cultivation of micro-organisms a subject of study.

2. *Influence of thickness of Fine Sand.*—That the thickness of the filtering stratum should exercise an important influence on the number of micro-organisms passing through the filter, will be sufficiently obvious to every one. In referring to his laboratory experiments on filtration, the author has already pointed out that comparatively thin strata of various materials are capable of largely, and sometimes of wholly, removing the micro-organisms in the water passing through them, but that this power is gradually lost; it is only reasonable to suppose that a thicker stratum will lose this power less rapidly than a thinner one. In estimating the thickness of the filtering stratum, the fine sand only should be taken into consideration, as it is only this portion of the filter which can have any effect in the removal of micro-organisms.

3. *Influence of Rate of Filtration.*—That the removal of micro-organisms is less perfect when the rate of filtration is increased, and *vice versa*, has been illustrated by the results obtained in the experiments already referred to.

4. *Influence of Renewal of Filter-beds.*—As already pointed out, even the most perfect filtering media sooner or later lose their power of retaining micro-organisms, and hence the importance of frequent renewal is sufficiently apparent.

In considering how the differences in these various factors, which the statistics of the Water Companies exhibit, may be expected to influence the results obtained in the removal of the micro-organisms, attention must be restricted to the five companies drawing water from the Thames, as it is only these which have approximately the same raw material to deal with; for from the above table it is seen that the amount of organic life found in the River Lee at the intake of the East London Company is very different from that in the Thames at Hampton, and the difference in the case of the New River Company is doubtless even still greater, besides the problem being there complicated by the admixture of a very considerable proportion of deep well-water.

The close proximity of the intakes of the five Thames companies, however, furnishes a favorable opportunity for instituting a comparison.

The factors in the mode of working, which have been pointed out as of special importance in exercising an influence upon the result obtained, are given in the table on page 326, the figures being taken from the statistical table given in Sir F. Bolton's "London Water Supply," 1884.

From this the general order of merit can be deduced, by adding these figures together for each company, and arranging them according to their average position, thus:

| Companies. | Average Position. | Order of Merit. |
|---|---|---|
| Chelsea..... | 2.25 | 2 |
| West Middlesex... | 1.5 | 1 |
| Southwark..... | 2.5 | 3 |
| Grand Junction... | 3.75 | 4 |
| Lambeth..... | 4.0 | 5 |

From the theroetical considerations here instituted, it would be anticipated, therefore, that dealing with the same raw material, the West Middlesex Water

More Important Factors in Mode of Treatment Practiced by Thames Water Companies.

| Name of Company. | Average Daily Supply, in Millions of Gallons. | Available Storage Capacity, in Millions of Gallons. | Average Storage in Days (Calculated.) | Rate of Filtration per Square Foot in Gallons per Hour. | Thickness of Fine Sand. | Renewal of Filter Beds (Calculated). Acreage Cleaned per Month. |
|---|---|---|---|---|---|---|
| | | | | | Ft. Ins. | Total Acreage. |
| Chelsea | 9.5 | 140.0 | 14.7 | 1.75 | 4 6 | 0.59 |
| West Middlesex | 12.8 | 117.5 | 9.2 | 1.5 | 3 | 0.90 |
| Southwark | 19.9 | 66.0 | 3.3 | 1.5 | 3 0 | 0.90 |
| Grand Junction | 14.1 | 64.5 | 4.6 | 1.75 | 2 6 | 0.81 |
| Lambeth | 14.2 | 128.0 | 9.0 | 2.0 | 3 0 | 0.50 |

By means of this table the companies may now be classified with respect to each of the four factors in question, thus:

| Company. | Storage Capacity. | Thickness of Fine Sand. | Rate of Filtration. | Renewal of Filter-beds. |
|---|---|---|---|---|
| Chelsea | 1 | 1 | 3 | 4 |
| West Middlesex | 2 | 2 | 1 | 1 |
| Southwark | 5 | 3 | 1 | 1 |
| Grand Junction | 4 | 5 | 3 | 3 |
| Lambeth | 3 | 3 | 5 | 5 |

Company should, on the whole, obtain the best average result, from a biological point of view, and that the results obtained by the other four companies would follow in the order of Chelsea, Southwark, Grand Junction, and Lambeth. On comparing this series with the number of micro-organisms found during the last four months (September to December) of the past year, it will be seen that this series is in precise accordance with the results obtained, thus:

| | Average Number of Micro-organisms found during the four months, Sept.-Dec., 1885, in 1 cubic centimeter. |
|---|---|
| West Middlesex | 6 |
| Chelsea | 15 |
| Southwark | 37 |
| Grand Junction | 64 |
| Lambeth | 70 |

The same series is obtained if the results are taken over the whole year; but in that case the figures for the Grand Junction and for the Southwark in March must be omitted, as on these occasions accidental contamination of these supplies had taken place, an exceptionally large number of micro-organisms being found in these months.

This coincidence between theory and practice most conclusively proves that in attempting the removal of micro-organisms from water it is no longer necessary to work in the dark, but that the problem is as tangible as the removal of those larger suspended particles which have for so long past occupied the attention of waterworks-engineers. The only difference between the two, is that the larger suspended particles are visible to the naked eye, whilst these minute living particles require the assistance of science

APPENDIX.—MICRO-ORGANISMS IN 1 CUBIC CENTIMETER OF METROPOLITAN WATERS.

| | 1885. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | May. | June. | | Sept. | Oct. | Nov. | Dec. |
| River Thames at Hampton... | — | — | — | — | — | — | 1,644 | 714 | 1,866 | 4,650 |
| Chelsea | 8 | 23 | 10 | 14 | 22 | 81 | 13 | 34 | 33 | 9 |
| West Middlesex | 2 | 16 | 7 | 3 | — | 26 | 2 | 2 | 5 | 15 |
| Southwark | 13 | 26 | 246 | 24 | — | 47 | 18 | 24 | 32 | 73 |
| Grand Junction | 382 | 57 | 28 | 3 | 21 | 18 | 43 | 40 | 40 | 134 |
| Lambeth | 10 | 5 | 69 | 30 | — | 38 | 103 | 26 | 26 | 124 |
| RIVER LEE. | | | | | | | | | | |
| River Lee at Chingford Mill.. | — | — | — | — | — | — | — | — | 954 | 2,831 |
| New River | 7 | 7 | 95 | 3 | — | 27 | 3 | 2 | 11 | 18 |
| East London | 25 | 39 | 17 | 121 | — | 22 | 29 | 53 | 14 | 317 |
| DEEP WELLS. | | | | | | | | | | |
| Kent (well at Deptford) | — | — | — | — | 6 | — | — | 6 | 8 | 5 |
| Kent (Supply) | 10 | 41 | 9 | 20 | 26 | — | 14 | 18 | — | 7 |

SUMMARY OF FILTRATION EXPERIMENTS.

| Name of Material. | Initial Efficiency. | Rate of Filtration. | Efficiency after | | Rate of Filtration. | Efficiency after | | Rate of Filtration. |
|---|---|---|---|---|---|---|---|---|
| | Reduction per cent. | Gal. pr. sq. ft. pr. hr. | | | Gal. pr. sq. ft. pr. hr. | | | Gal. pr. sq. ft. pr. hr. |
| Ferruginous greensand | 100 | — | 13 days. Reduction of | 88 | 0.73 | 1 month. Reduction of | 39.0 | 1.14 |
| Animal charcoal | 100 | — | 12 days. Reduction of | 100 | 0.46 | 1 month. Increase of | 447.0 | 0.86 |
| Iron sponge | 100 | — | 12 days. Reduction of | 100 | 0.40 | 1 month. Reduction of | 99.8 | 0.45 |
| Brick-dust (pulverized red brick) | 76 | — | — | | — | 5 weeks. Reduction of | 93.0 | 0.48 |
| Coke (A) | 100 | — | — | | — | 5 weeks. Reduction of | 98.5 | 0.50 |
| Coke (B) | 2d day 100 | 0.89 | 3 weeks. Reduction of | 85 | 1.32 | — | | — |
| Coke (C) | 2d day 100 | 0.67 | 3 weeks. Reduction of | 90 | 1.03 | — | | — |
| Vegetable charcoal (A) | 2d day 100 | — | — | | — | — | | — |
| Vegetable charcoal (B) | 2d day 100 | 0.22 | — | | — | 1 month. Reduction of | 95.0 | 0.22 |
| Vegetable charcoal (C) | 2d day 100 | 0.26 | 3 weeks. Reduction of | 77 | 0.59 | — | | — |

to render them apparent. It will also be obvious from the facts brought forward, how necessary it is that these micro-organisms should now receive the careful attention of waterworks engineers, for upon them must ultimately depend the success in practice of the improved processes indicated by scientific research. It is necessary that waterworks-engineers themselves should become experimenters in this field, with the view of ascertaining how their processes may be carried out so as to yield the best results. It is not intended by this that they should be expected to carry out the actual bacteriological operations themselves, for which special training is necessary, but that they should sufficiently acquaint them-

selves with the subject in order to carry out the necessary arrangements for such experiments on the large scale.

It must be pointed out that valuable as are the results obtained when the whole supply of each company is thus periodically submitted to examination, a much deeper insight into the working of the filters is to be obtained by the frequent examination of each individual filter-bed. The examination of the whole supply only gives a summary of the working, and the individual conditions more or less obliterate each other, but by a careful periodical examination of each filter-bed, any defect in a detail of the process of purification would be at once detected and remedied. In fact, it is desirable that the life-history of each individual filter-bed should be carefully studied both for present and future guidance.

The regular biological examination of the water-supply of Berlin has now been carried out for upwards of a year under Dr. Koch, and the importance of this supervision is there duly recognized both by the State authorities and by the water-works-engineers. England has hitherto occupied the first place in the world for the excellence of her sanitary institutions; this place she still maintains; but in future, unless practice goes more hand-in-hand with science, there is every prospect that, as already in industrial prosperity, so in sanitation, she will year by year lose ground in favor of her aspiring neighbors.

The principal conclusions to be drawn from the experiments referred to, are:

I. That the complete removal of micro-organisms from water by filtration is unattainable without frequent renewal of the best filtering materials, and duly restricting the rate of filtration.

II. That a very great reduction in the amount of organized matter in water may be accomplished by filtering materials which have hitherto been generally regarded as almost ineffectual.

III. That organized matter is to a large extent, and sometimes to a most remarkable extent, removable from water by agitation with suitable solids in a fine state of division, but that such methods of purification are unreliable.

IV. That chemical precipitation is attended with a large reduction in the number of micro-organisms present in the water in which the precipitate is made to form and allowed to subside.

V. That if subsidence, either with agitation or after precipitation, be continued too long, the organisms first carried down may again become redistributed throughout the water.

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PROPOSED INCREASE OF DUTY IN RUSSIA ON FOREIGN COAL.—Yielding to the clamor of the Russian protectionist press, the Minister of Finance has recommended to the Council of Ministers that the duty on foreign coal imported, *viâ* the Black Sea, should be raised from two copecks per pood to three copecks. This is the second advance that has taken place during the last few years, and is probably only the forerunner of further enhancements. The jump from 3s. a ton to 4s. 6d. is hardly what the Russian press expected, as a demand had been made for a duty of nearly 6s.; but it will give the Donetz coal an opportunity of showing whether it can rise to the occasion and compete with the foreign article or not. Last time the duty was so arranged that the foreign coal, weighted with the new tariff, should be just a trifle dearer than Donetz coal. Directly the duty was imposed, however, the price of foreign coal fell—cheaper freights favoring the downward movement—and ever since English coal has been selling at Odessa 2s. or 3s. cheaper a ton than the native fuel. The duty proposed is not sufficiently heavy to give the latter any advantage over the former, and on this account the press is angry that the minister should not have gone a little further in the path of protection while at it. In the Baltic, the minister proposes no alteration of the duty at all, leaving it at 9d. per ton as at present. This policy is easily understood. The South Russian coalfields are not sufficiently developed to furnish a cheap supply of fuel for the Baltic region, and the various engineering undertakings which the Government has favored with subsidies or bounties, would have to close their establishments if deprived of cheap coal. In all likelihood the tariff in the Baltic will be left as it is for several years to come, until railway communication between the Donetz region and St. Petersburg is more improved, or the coalfields of the Vistula province more developed. We believe that the latter will tell, at no distant date, upon the coal market of North Russia, particularly now that a German syndicate has taken over the Ivangorod-Dombrova Railway, tapping the Polish coalfields. The Vistula coal is very abundant and of better quality than Donetz coal, and already commands a ready sale on the Polish railways and in the factories of Warsaw. Most of the mines are in German hands, and efforts are being made to secure favorable railway rates for sending it to Riga, Revel, and other Baltic ports. When matters are ripe the Russian Government will assuredly impose a heavier duty on foreign coal imported *viâ* the Baltic, probably assimilating the tariff with that prevailing in the Black Sea.

# NEW PRACTICAL FORMULAS FOR THE RESISTANCE OF SOLID AND BUILT BEAMS, GIRDERS, ETC., WITH NUMEROUS PROBLEMS AND DESIGNS.

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Written for Van Nostrand's Engineering Magazine.

## I.

By practical formulas is meant, those which are both simple and accurate, those which can be easily and safely used.

It is well known that the moment of inertia is a factor in most formulas involving the moment of resistance; and that we usually arrive at the latter through the former. Otherwise we have little interest in the moment of inertia. The moment of resistance, however, does express something fundamentally essential; and the best formulas for the same are therefore very desirable. This will be clear as we proceed.

Accurate formulas for the moment of resistance of all usual sections are well known, but, being more or less complex, and therefore unmanageable by many Bridge Engineers and Architects, other formulas more simple and *seemingly* quite correct, but unfortunately very erroneous, have come into general use.

The main objects of this treatise are:

1°. To deduce and set forth simple and accurate formulas for the resistance of beams, girders, etc.

2°. To point out, to some extent, the errors of the formulas in general use, and the reasons for the existence of these errors.

3°. To apply the new formulas in the examination of existing cases and in designing floor beams, track stringers, etc.

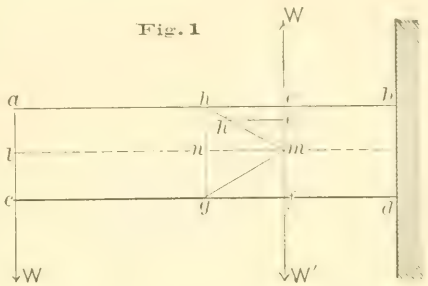
The nature and importance of the moment of resistance will be best understood by first considering the forces that, in ordinary cases at least, produce it. We may then advantageously confine the discussion to the moment of resistance itself.

I. Let *abcd* (Fig. 1) represent a beam fixed at the end *bd* and loaded with a weight W at the free end *ac*. Length of beam $=ab=l$.

It it is evident that the fibers on the lower part of the beam will be compressed, and those on the upper part extended; and that, as a consequence, the beam will bend.

The fibers on some intermediate plane, *em*, will therefore be neither compressed nor extended. This plane is called the neutral plane or axis.

Fig. 1




The main points of the common theory of the resistance of beams to external forces in general are:

1°. The extensions and compressions of the fibers are directly as the forces that produce them.

2°. The forces, and therefore the compressions and extensions also, are directly as their distance from the neutral axis.

3°. The neutral axis passes through the center of gravity of the section.

We are now prepared to explain the nature of the equilibrium between the external and internal forces.

Consider any section, *ef*, perpendicular to the axis of the beam.

Let $b$=the breadth, $d$=the depth and $x$=lin, the distance from the free end to any section considered.

We will first consider the external forces. Take moments about $m$. The moment of W is $Wx$, and this can be balanced only by the moments of the strains upon the fibers both above and below $m$, about the same point $m$. The force W also produces a shearing or cross strain,

equal to W, upon every vertical section of the beam; and this strain can be met only by an equal stress upon the fibers in the same direction. By applying the equal and opposite forces W and W′ on the section *ef*, the external strains may be made more apparent to some.

Since these forces balance each other, they cannot disturb, or in any way change the existing state of things. These forces, however, with the force W at the end of the beam, constitute the couple W$x$W, whose moment is $W \times lm = Wx$; and the force W′, which creates the shearing upon the section *ef* and upon all sections of the beam.

We see that the shearing strain in a beam loaded as in Fig. 1, is constant on

Fig. 2

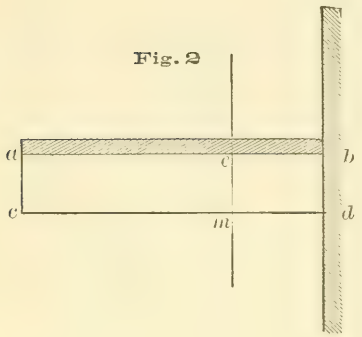



Fig. 3

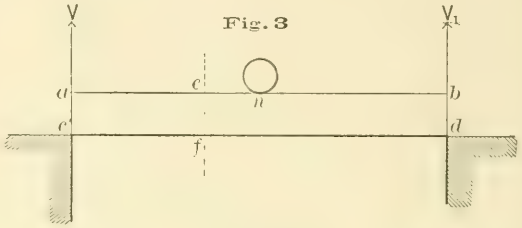
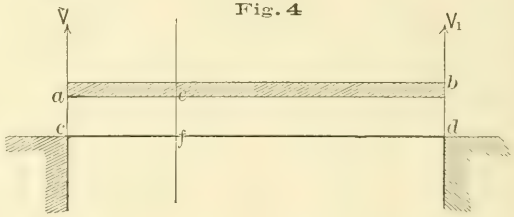



Fig. 4




all sections, but that the moment of strain W$x$ increases with $x$, or the distance of the section considered from the load. Hence at the fixed end the moment is a maximum, the fibers there are most strained, and the section at the fixed end is the "dangerous" section.

At the fixed end we have, the maximum moment $= M_0 = Wl$. (1)

Having found the moment of external forces upon a beam fixed at one end and loaded with a weight W at the free end, we will proceed to find an expression for the moment of internal forces.

Let $s$ = the strain upon a unit of fibers at $e$ take $eh = s$. Were all the fibers on the cross section *em* of the upper half of the beam equally strained it is plain that the volume of the parallelopiped, whose face is *ehnm* and depth is $b$ (the breadth of the beam), would represent the tension upon the upper half of the beam. Since, however, the strains decrease regularly from the outermost fiber to the center, where the strain is zero, it follows that the strain on the upper half of the beam will be represented by the wedge whose face is *ehm* and breadth is $b$.

The resistance to tension is therefore equal to $\frac{1}{2}\ em \times eh \times b = \frac{1}{4}\ bds$.

The moment of this resistance is equal to this value multiplied by the distance of the center of gravity of the wedge from the center of the beam, which is equal to $\frac{2}{3}em = \frac{1}{3}d$. Hence the moment of resistance is equal to $\frac{1}{4}bds \times \frac{1}{3}d = \frac{1}{12}bd^2s$.

Since the moment of resistance to compression is the same, the total moment of resistance is therefore $M = \frac{1}{6}bd^2s$. (2)

Again, the moment of resistance of the cross section *em* about its lower edge at $m$ is, as just found, $\frac{1}{12}bd^3s = \frac{1}{3}b(\frac{1}{2}d)^2s$ (3).

This shows that the moment of resistance of a rectangle about one edge is equal to one-third ($\frac{1}{3}$) the breadth multiplied by the square of the depth and by the modulus of strain.

In the case of a beam, fixed at one end and loaded at the free end, we have seen that the moment of strain on the cross section at the fixed end of the beam is $Wl$; and that the moment of the resisting forces on the fibers is $\frac{1}{6}\ bd^2s$, the notation being as heretofore. These quantities must be equal, and hence

$$Wl = \frac{1}{6}bd^2s \qquad (4)$$

In all cases, the moment of external forces called the "bending moment" must be equal to the moment of internal forces, that is to the "moment of resistance."

*S* of course increases with W, and whether in any given case, *s* is as great as the material will stand, in which case it is at the point of rupture, depends upon the load W, that the beam has to sustain, and upon the area and form of the cross section of the beam.

For a *given* load W, we solve for *s* and find,

$$S=\frac{Wl}{\frac{1}{6}bd^2}=\frac{6Wl}{bd^2} \qquad (5)$$

For a given or allowable value of *s* we solve for W and find

$$W=\frac{\frac{1}{6}bd^2s}{l}=\frac{bd^2s}{6l} \qquad (6)$$

CASE II.

Let the beam be fixed at one end and uniformly loaded.

Let $w$=load per unit of length.

W=total load. Other notation as before.

Consider a section t *em.*

Load on $ae=wx$. The center of gravity of the load is at a distance from *e* equal to $\frac{1}{2}x$. Hence the moment of the load about *e* is equal to

$$M=wx\times\tfrac{1}{2}x=\tfrac{1}{2}wx^2.$$

At the fixed end

$$x=l \text{ and } M_0=wl\times\tfrac{1}{2}l=\tfrac{1}{2}Wl \qquad (7)$$

CASE III.

Let the beam (Fig. 3) be supported at the ends and carry a weight W at the middle point *u*. Notation as before. One half of the load will be carried to each support. Hence the reactions V and $V_1$ are each equal to $\frac{1}{2}W$.

The moment of strain on any section *ef* is $\frac{1}{2}Wx$. The greatest strain on the left hand half of the beam corresponds to the greatest value $x$ can have for that half, and which is equal to $\frac{1}{2}l$. Hence the greatest strain on that half, and therefore on the beam is,

$$M_0=\tfrac{1}{2}W\times\tfrac{1}{2}l=\tfrac{1}{4}Wl \qquad (8)$$

CASE IV.

Let the beam (Fig. 4) be supported at the ends, and uniformly loaded as in Case II. Notation as usual. We evidently have $V=V_1=\frac{1}{2}W$. Hence at any section *ef* we have the moment of $V=\frac{1}{2}Wx$. The load between V and *e* is equal to $wx$, and its lower arm is $\frac{1}{2}x$; hence the moment of that load is $\frac{1}{2}wx^2$.

Since this moment acts in the opposite direction from the moment of V, their difference gives the moment on the section. Hence $M=\frac{1}{2}Wx-\frac{1}{2}wx^2$. Putting $x=\frac{1}{2}l$, this becomes

$$M_0=\tfrac{1}{4}Wl-\tfrac{1}{8}Wl^2=\tfrac{1}{8}Wl \qquad (9)$$

To prove that equation (9) gives the greatest strain upon the left hand half of the beam, and consequently upon the beam, since the beam is symmetrical about the center, put $x=\frac{1}{2}l-a$ in the value for M and we have:

$$M=\tfrac{1}{2}W(\tfrac{1}{2}l-a)-\tfrac{1}{2}w(\tfrac{1}{2}l-a)^2=\tfrac{1}{4}Wl-\tfrac{1}{2}Wa \\ -\tfrac{1}{8}wl^2+\tfrac{1}{2}wla-\tfrac{1}{2}wa^2.$$

But $\frac{1}{2}wla=\frac{1}{2}Wa$ $\therefore$ $M=\frac{1}{4}Wl-\frac{1}{8}wl^2-\frac{1}{2}wa^2$ $=\frac{1}{8}Wl-\frac{1}{2}wa^2$,

which is less than $M_0$ given by (9).

Substituting $\frac{1}{2}l\pm a$ for $x$ will give precisely the same result and show that the strains are symmetrical with reference to the center, which, in the nature of the case, we know to be true, and that the strain is a maximum at the center.

Putting the differential coefficient of $M=\frac{1}{2}Wx-\frac{1}{2}wx^2$ equal to zero, we have,

$$\frac{dM}{dx}=\tfrac{1}{2}W-wx=o \quad \therefore x=\frac{\frac{1}{2}W}{w}=\tfrac{1}{2}l,$$

for the point of maximum strain as already found.

Comparing equations (1), (7), (8) and (9), we see that, for the same total load, in the four cases considered, the moments of strain upon the sections of greatest strain, and consequently the moment of stress upon the fibers, as well as the stress upon the fibers, are as the numbers 8, 4 2 and 1. Hence the beams are capable of carrying loads, disposed as shown, in the ratio of 1, 2, 4 and 8.

For example, a beam supported at the ends and uniformly loaded will carry eight times as great a load as the same beam will carry when fixed at one end and loaded at the free end.

In the first case, the shearing stress, which we will represent by S, is constant and equal to $S_1=W$ (10).

In the second case, the shearing stress

at any section *ef* is evidently equal to the load between the free end and that section, and is $S=wx$. This is a maximum at the fixed end and equal to

$$S_1=wl=W \qquad (11)$$

In the third case, since $V=\frac{1}{2}W$ and there is no load between V and the load at the middle, the shearing stress at all points of the beam is evidently equal to

$$S_1=\tfrac{1}{2}W \qquad (12)$$

In the fourth case the reaction $V=\frac{1}{2}W$ and as the load between the free end and the section *ef* is equal to $wx$, the shearing stress on that section is equal to $S=\frac{1}{2}W-wx$.

At the end this is a maximum and

$$S_1=\tfrac{1}{2}W \qquad (13)$$

At the middle $S=\frac{1}{2}W-w\frac{1}{2}l=o$.

*Example* 1.—Suppose the safe stress per square inch to be, $s=1200$ pounds, $l=16$ feet, $b=3$ inches, and $d=12$ inches. What weight, uniformly distributed, will the beam, supported at its ends, carry?

From equations (2) and (9) we have:

$$\tfrac{1}{8}Wl=\tfrac{1}{6}bd^2s \text{ or } \frac{W=4bd^2s}{3l}$$

$$=\frac{4\times3\times12^{-2}\times1200}{3\times16\times12}=3600 \text{ pounds.}$$

*Example* 2. — There are 9 joists $3''\times12''\times17'$ equally spaced, carrying 80 pounds per square foot on the floor of a bridge, which is 16 feet wide. What is the greatest strain per $\square''$ of fibers?

Each of the two outer joists carries but one-half as much as each of the others. Hence each of the middle joists carries $\frac{1}{8}$ of the total load or

$$\frac{80\times16\times17}{8}=2720$$

Now $2720=\frac{4bd^2s}{3l}$ and $s=963$ pounds.

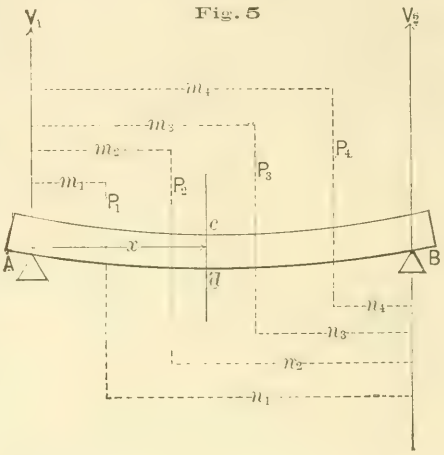
### Other Cases of Loading.

Case V.—A beam resting upon two supports and loaded at any number of points. If a beam is loaded in any manner it is only necessary to find the moments of all the forces in reference to the center of the section considered, and place the algebraic sum equal to the moment of resistance of the section. In Fig. (5), let the weights $P_1$, $P_2$, $P_3$, etc. rest upon the beam at distances respectively equal to $m_1$, $m_2$, $m_3$, etc. from one support; and $n_1$, $n_2$, $n_3$, etc. from the other. Let $l$=the distance between the supports, and $V_1$ and $V_2$ the reactions at the supports. Consider any section, *cd*, distant $x$ from the support A. The sum of the moments of the forces on the section *cd* is

$$V_1\times-P_1(x-m_1)-P_2(x-m_2)-\text{etc.}$$

to include all the P's between A and *cd*.

Fig. 5




For rectangular beams we have therefore

$$V_1x-P_1(x-m_1)-P_2(x-m_2)-\text{etc.}=\tfrac{1}{6}bd^2s. \qquad (14)$$

To find $V_1$ take moments about B and find,

$$V_1l=P_1n_1+P_2n_2+P_3n_3+\text{etc.}=\Sigma Pn$$

$$\therefore V_1=\frac{\Sigma Pn}{l}\text{; similarly } V_2=\frac{\Sigma Pm}{l}.$$

Also $V_1+V_2=P_1+P_2+P_3+\text{etc.}=\Sigma P$.

In case of a single weight $P_1$, Fig. (6), the preceding formulas give,

$$V_1=\frac{P_1n_1}{l},\ V_2=\frac{P_1m_1}{l} \text{ and}$$

$$V_1+V_2=\frac{P_1}{l}(n_1+m_1)=P_1.$$

From these we have for any section distant $x$ from A, the moment equal to

$$M=V_1x=\frac{P_1}{l}n_1\times. \qquad (15)$$

Similarly for a point distant $x$ from B,

$$M = V_2 x = \frac{P_1}{l} m_1 x. \qquad (16)$$

Since $\frac{P_1}{l}$ is constant we see that the strain on *any* section varies as the product of the end segments, into which the beam is divided by the weight and the section.

Fig. 6

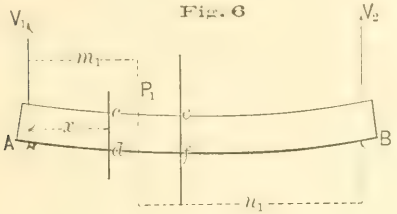
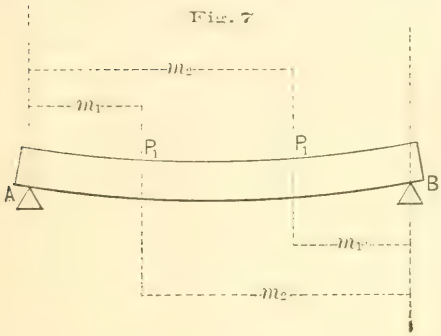



Fig. 7




Again, making $x$ the same in (15) and (16), we see that sections on opposite sides of the weight and equally distant from the supports, are strained in the ratio of the segments into which the weight divides the beam.

In case of two equal weights $P_1$ and $P_1$, symmetrically placed upon the beam as shown.

We have $V_1 = \frac{P_1 m_2 + P_1 m_1}{l} = P_1$.

Similarly $V_2 = P_1$.

For any section between A and $P_1$ the moment is $M' = V_1 x = P_1 x$, which is less than $P_1 m_1$.

For any section between the weights, the moment $= V_1 x - P_1(x - m_1)$

$$= P_1 x - P_1(x - m_1) = P_1 m_1 \qquad (17)$$

The strain therefore increases from zero at either support to the adjacent weight, and remains constant between the weights.

If, in Fig. 8, $pc$ or $p'c'$ represents the moment of strain under the weights, any ordinate as $ef$ will represent the strain at the point $e$.

For a uniformly distributed load of $2P_1$, eq. (9) gives,

$$M' = \tfrac{1}{8} l (2P_1) = \tfrac{1}{4} P_1 l \qquad (18)$$

Comparing eqs. (17) and (18), we see that the greatest strain in the case of a uniformly distributed load is to that of the same load when placed as in Fig. 7, as $\frac{1}{4}l$ is to $m_1$.

Fig. 8

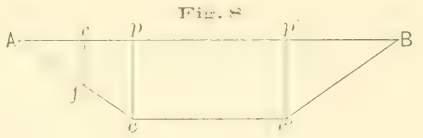



Fig. 9




Since tables are usually arranged to give the strains for a uniformly distributed load, on floor beams, track stringers, etc., it becomes important to notice and provide for increased strains due to concentrated loads as above.

*Example.*—A floor beam of a railway bridge is 14 feet long between supports and carries a single track, the gauge being 4 feet and 8 inches. The beam is designed to carry a distributed load just equal in amount to the eccentric load upon it. What is the capacity of the beam?

We have $m_1 = \frac{14 - 4\frac{2}{3}}{2} = 4\frac{2}{3}$. The load on the beam is, $\frac{m_1}{\frac{1}{4}l} = \frac{4m_1}{l} = \frac{18\frac{2}{3}}{14} = \frac{4}{3}$ times the load it is able to carry. Hence it is able to carry $1 \div \frac{4}{3} = \frac{3}{4}$ of the given load; or it has a capacity of 75%.

It is worthy of notice that the greatest load that can come upon a floor beam, for example, for a given weight of engine per foot, depends upon the relative lengths of panel and wheel space, that is, the distance between consecutive pairs of wheels.

We will show that, in general, a load greater than the weight of the engine for a panel length, can come upon a floor beam; and we will deduce a general expression for the load and the excess of load over a panel load.

Let $l$ = a panel length.

$x$ = wheel space.

$w$ = weight of engine per foot.

$\therefore wx$ = weight on a pair of wheels.

and $wl$ = weight of engine per panel length.

Let $l \geqq nx$ and $l < (n+1)x$, $n$ being an integer.

In Fig. 9, let *ab*, *cd*, *ef*, etc., represent the floor beams, *gk* and *hl* the track stringers, and the circles the position of the wheels. Consider the load on *cd*. Let a pair of wheels rest on *cd*. To find the load on *cd* we have $wx$ resting directly upon *cd*, while $\frac{l-x}{l}\,wx$ comes upon *cd* from each of the adjacent pairs of wheels, distant $x$ from *cd*; or $2wx\frac{l-x}{l}$ from both pair. Similarly $2wx\frac{l-2x}{l}$ is supported by *cd* from the next two pairs of wheels, distant $2x$ from *cd*, etc., etc.

Hence the total load on *cd* is,

$$L = wx + 2wx\frac{l-x}{l} + 2wx\frac{l-2x}{l} + 2wx\frac{l-3x}{l} + \text{etc.} \ldots\ldots 2wx\frac{l-nx}{l}$$

or $L = wx + 2wx(1+1+1+1+\text{etc. to } n \text{ terms}) - \frac{2W}{l}(^2x2\times{}^2x3x^2 + \text{etc. to } nx^2)$

$$= wx(2n+1) - \frac{w}{l}n(n+1)x^2 \qquad (19)$$

Putting the differential coefficient of this equal to zero we find

$$(2n+1) - \frac{2n(n+1)}{l}x = 0$$

$$\text{or } x = \frac{(2n+1)l}{2n(n+1)} \qquad (20)$$

Substituting this value of $x$ in (19) and reducing, we find the maximum load on

$$cd = L_0 = Wl\frac{(2n+1)^2}{4n(n+1)} = Wl\frac{4n(n+1)+1}{4n(n+1)}$$

$$= Wl + \frac{Wl}{4n(n+1)} \qquad (21)$$

$L_0$ is therefore greater than $Wl$; but the excess over $Wl$ decreases as $n$ increases. For $n=0$ we have $L_0 = \frac{Wl}{0} = \infty$.

But $n=0$ gives from above $x = \frac{l}{0} = \infty$ and

$\therefore wx = \frac{wl}{0} = \infty$ as it ought.

From (20), $l - nx = \frac{l}{2(n+1)}$ (22)

This shows the space between the $n$th pair of wheels from *cd* and the adjacent floor beam.

For $n=1$ (20) and (22) give, $x = \frac{2}{4}l$, and $l - x = \frac{1}{4}l$.

For $n=2$ (20) and (22) give, $x = \frac{5}{12}l$, and $l - 2x = \frac{1}{6}l$.

For $n=3$ (20) and (22) give, $x = \frac{7}{24}l$, and $l - 3x = \frac{1}{8}l$.

For $n=1$ we have $L_0 = \frac{9}{8}wl$.

For $n=2$ we have $L_0 = \frac{25}{24}wl$.

For $n=3$ we have $L_0 = \frac{49}{48}wl$.

For $n=4$ we have $L_0 = \frac{81}{80}wl$, etc.

These results show that the excess of load is slight, except for short panels and wide wheel spaces, in which case it may amount to $\frac{1}{8}$ or $12\frac{1}{2}\%$ of a panel load.

*Example.*—In a railway bridge, the length of panels is $l=10$ feet; the distance between pairs of wheels is $x=7\frac{1}{2}$ feet. Load, 4,000 pounds per foot. Find the greatest load supported by a floor beam and the excess over a panel load.

The load supported is

$\frac{9}{8}wl = \frac{9}{8}\times 4{,}000\times 10 = 45{,}000$ pounds.

A panel load is

$wl = 4{,}000\times 10 = 40{,}000$ pounds.

The excess is therefore

$\frac{1}{8}wl = 500\times 10 = 5{,}000$ pounds.

To prove that the maximum strain occurs when a pair of wheels rests upon the beam as in Fig. 9, let us suppose the engine to move to the right (say) a distance $= \frac{l}{2(n+1)}$ [see Eq. (22)], so that it will occupy the position shown in Fig. 10.

It is evident that only a part of the weight, $wx$, resting upon *cd* in Fig. 9 rests upon *cd* in Fig. 10, and that so far as the other weights are concerned, the increased load upon *cd* from the weights at the left of *cd* is exactly balanced by the

decreased load upon $cd$ from the weights at the right of $cd$. The load upon $cd$ is less than in Fig. 9, by

$$\frac{\frac{l}{2(n+1)}}{l}\ wx=\frac{(2n+1)l}{2n(n+1)2(n+1)}n$$

$$w=\frac{2n+1}{4n(n+1)^2}w \quad (23)$$

2°. Again let us suppose the engine to move from the position shown in Fig. 10 to that shown in Fig. 11. From what has been said, it is evident that no change in the load upon $cd$ has taken place.

3°. Finally we will suppose the engine to move from the position of Fig. 11 to that of Fig. 12. It is evident that this movement is the reverse of the first, and that the load will increase therefore during this change, precisely as it decreased during the first.

Fig. 10

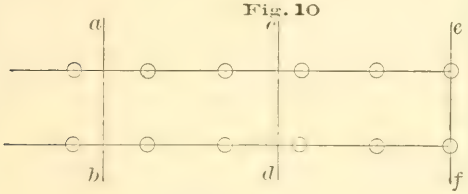
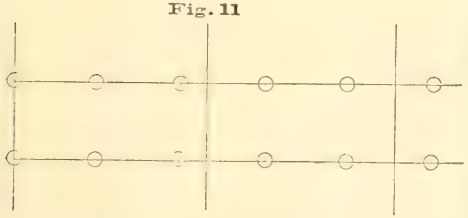



Fig. 11



In Fig. 13, let $bb'$ represent a wheel space, then the ordinate $ab$ represents the maximum load on the beam corresponding to Fig. 9, while $cd$ and $c'd'$ represent the minimum loads corresponding to Figs. 10 and 11, and $a'b'$ the maximum corresponding to Fig. 12, which is the same as Fig. 9.

We see that while the engine advances a wheel space, the load upon a beam decreases for a part of that distance, remains constant during the second part, and increases again during the third part. The smallest loads upon the floor beam ($cd$), corresponding to the positions shown in Figs. 10 and 11, or any position between these two, are not minimum loads, but simply the loads corresponding to certain positions of the engine, when the wheels are spaced to produce a maximum load.

To find the wheel space for a minimum load upon a floor beam, when a pair of wheels is over a beam. Eq. (20) gives the value of $x$ for a maximum load.

Put $x=\frac{2n+1}{2n(n+1)}l+a$ in (19) and we find

$$L'=\frac{(2n+1)^2}{2n(n+1)}wl+wa)2n+1)$$

$$-\frac{w}{l}n(n+1)\left(\frac{2n+1}{2n(n+1)}l+a\right)^2$$

$$=\frac{(2n+1)^2}{4n(n+1)}wl-\frac{w}{l}n(n+1(a^2 \quad (24)$$

Eqs (21) and (24) give,

$$L_0-L'=\frac{w}{l}n(n+1)a^2 \quad (25)$$

Fig. 12

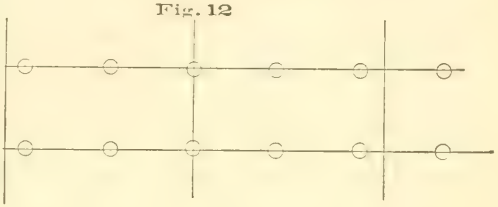
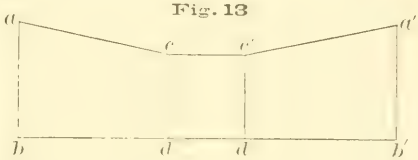


Fig. 13




This shows that the greater $a$ is, the less the load upon the beam.

Now $l=nx+(l-nx)=n\left(x+\frac{l-nx}{n}\right)$

This shows that if the wheel space is increased by the $n$th part of the excess of a panel length over a wheel space, $n$ times the increased wheel space will equal a panel length.

Hence $a$ cannot exceed $\frac{l-nx}{n}$

But Eq. (22) gives,

$$\frac{l-nx}{n}=\frac{l}{2n(n+1)}=a \quad (26)$$

Putting this value of $a$ in (24) we get,

$$L'=\frac{(2n+1)^2}{4n(n+1)}wl-\frac{w}{l}n(n+1)\frac{l^2}{4n^2(n+1)^2}$$

$$=\frac{(2n+1)^2}{4n(n+1)}wl-\frac{1}{4n(n+1)}wl=wl \quad (27)$$

The minimum load upon the beam corresponds to wheel spaces equal to a panel length, or to an aliquot part of the same; the minimum load being equal to a panel load.

It is not so necessary to consider the increased strains upon floor beams, etc., in case of a double track, though we may just as easily do so; for, in the first place, the loads upon the beams are much more nearly distributed than in the case of a single track; and, furthermore, the loads on the two tracks would rarely occupy the same position with reference to the floor beam.

### A Partial Uniform Load.

Let a beam be uniformly loaded over *any* portion of its length.

Fig. 14

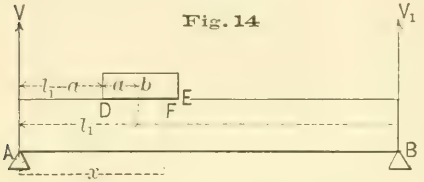
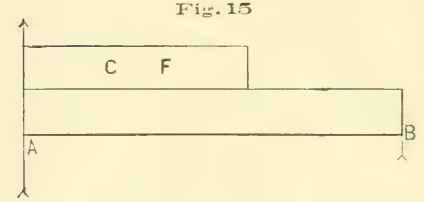



Fig. 15




Let $l$=AB, the length of the beam,
$2a$=DE, the length of the load,
$x$=AF, the distance to any section,
C=the center of the load,
$l_1$=AC, $w$=load on a unit of length,
V=the reaction of support A.

Then $AD=l_1-a$ and $DF=x-(l_1-a)$
$=x+a-l_1$.

The load on $DF=w(x+a-l_1)$.

The load on $DE=2wa$.

By the principle of moments,

$$Vl=2wa(l-l_1) \quad \therefore V=2wa\left(1-\frac{l_1}{l}\right)$$

The moment of stress at F is,

$M=Vx-w(x+a-l_1)\frac{1}{2}(x+a-l_1$
$=Vx-\frac{1}{2}w(x+a-l_1)^2$,

or $$M=2awa\left(1-\frac{l_1}{l}\right)x-\frac{1}{2}w(x+a-l_1)^2 \quad (28)$$

That value of $x$ which makes (28) a maximum gives the position of the dangerous section.

Differentiate, place equal to zero, and solve for $x$ and find,

$$x=a\left(1-\frac{2l_1}{l}\right)+l_1=l_1\left(1-\frac{2a}{l}\right)+a$$
$$=a+l_1-\frac{2al_1}{l} \quad (29)$$

If $l_1=\frac{1}{2}l$, $\quad x=l_1$.
If $l_1<\frac{1}{2}l$, $\quad x>l_1$.
If $l_1>\frac{1}{2}l$, $\quad x<l_1$.

These results show that the maximum strain is at the center of the loading only when the center of the loading is over the center of the beam, and that in all other cases it is nearer the center of the beam than the center of the loading is.

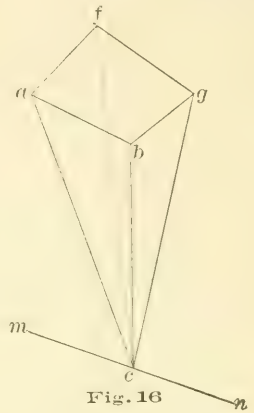



Fig. 16

To find the relative positions of the centers of loading and dangerous section, put $l_1=\frac{1}{2}l\pm d$; then

$$x=a\left(1-\frac{l\pm 2d}{l}\right)+\frac{1}{2}l\pm d=\pm d\frac{l-2a}{l}\pm\frac{1}{2}l.$$

Now $x-\frac{1}{2}l=\pm d\frac{l-2a}{l}$ and $l_1-\frac{1}{2}l=\pm d$.

Hence $$\frac{x-\frac{1}{2}l}{l_1-\frac{1}{2}l}=\frac{l-2a}{l} \quad (30)$$

which shows the ratio of the distances of the dangerous section and the center of loading from the center of the beam.

Differentiating (29) with respect to $l_1$ and also with respect to $a$, we find,

$$\frac{dx}{dl_1}=1-\frac{2a}{l} \quad (31)$$

which is positive; and

$$\frac{dx}{da}=1-\frac{2l_1}{l} \qquad (32)$$

which is positive for $l_1<\frac{1}{2}l$ and negative for $l_1>\frac{1}{2}l$.

Eq. (31) shows that $x$ increases and decreases with $l_1$.

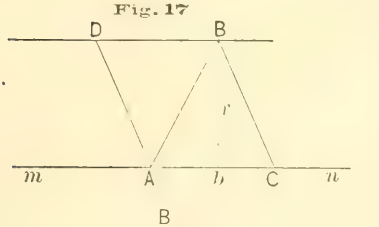
Eq. (32) shows that when $l_1<\frac{1}{2}l$, that is, when the center of loading is between the center of the beam and the origin, $x$ increases and decreases with $a$; but when $l_1<\frac{1}{2}l$, that is, when the center of loading is on the opposite side of the center of the beam from the origin, $x$ increases as $a$ decreases and vice versa.

The maximum strain for given values of $a$ and $l_1$ is found by substituting the value of $x$ from (29) in (28). We have

$$x=a+l_1-\frac{2al_1}{l} \quad \therefore x+a-l_1=2a\left(1-\frac{l_1}{l}\right)$$

Hence $$M_0=2aw\left(1-\frac{l_1}{l}\right)\left(a+l_1-\frac{2al_1}{l}\right)$$
$$-2a^2w\left(1-\frac{l_1}{l}\right)^2$$

Fig. 17



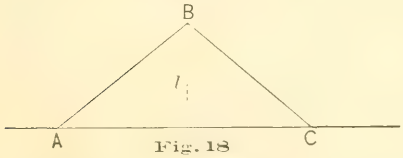




Fig. 18

$$=2aw\left(1-\frac{l_1}{l}\right)\left\{a+l_1-\frac{2al_1}{l}-a\left(1-\frac{l_1}{l}\right)\right\}$$

$$=2aw\left(1=\frac{l_1}{l}\right)\left(l_1-\frac{al_1}{l}\right)$$

$$=2awl_1\left(1-\frac{l_1}{l}\right)\left(1-\frac{a}{l}\right) \qquad (33)$$

The value of $a$ which will make (33) a maximum is found by differentiating the equation with reference to $a$. We thus find $1-\frac{2a}{l}=0$ or $2a=l$.

Hence the larger the load the greater the strain.

When $2a=l$, $l_1=\frac{1}{2}l$ and $M=.\frac{1}{2}wl^2\frac{1}{2}\ .\ \frac{1}{2}$ $=\frac{1}{8}wl^2=\frac{1}{8}Wl$, agreeing with Eq (9) as it ought.

Let $a=\frac{1}{4}l$ and $l_1=\frac{1}{4}l$

Then the strain at F is by (33),

$$M_{0_4}=\tfrac{1}{2}wl\ .\ \tfrac{1}{4}l_1\tfrac{3}{4}\ .\ \tfrac{3}{4}=\tfrac{9}{128}wl^2.$$

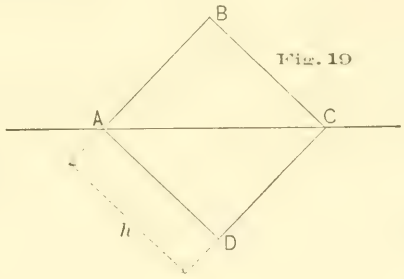
To find the strain at the center, we have the load$=\frac{1}{2}wl$; and $V=\frac{3}{4}\ .\ \frac{1}{2}wl=\frac{3}{8}wl$.

Taking moments about the center of the beam we have $M'=\frac{3}{8}wl\times\frac{1}{2}l-\frac{1}{2}wl\times\frac{1}{4}l$

$$=\frac{8}{128}wl^2$$

This shows that the strain at the dangerous section for this loading exceeds that at the center by $\frac{1}{8}$, or $12\frac{1}{2}\%$. This excess is the same as the maximum excess coming upon a floor beam from an undistributed load.

Fig. 19



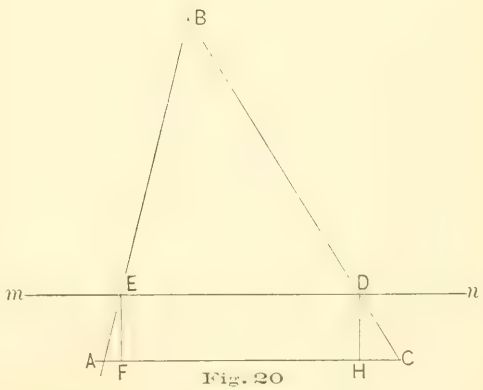




Fig. 20

We will now derive a general formula for the moment of resistance, after which we will deduce the moment of resistance of triangular and other cross sections.

Let $s$=strain on a unit of fibers, of any cross section, most remote from the neutral axis.

$d$=distance from the neutral axis to the most remote fiber.

$y$=distance to any fiber.

$\delta$=an elementary area.

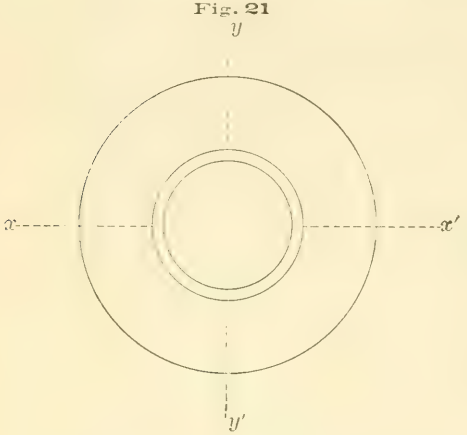
Then $\frac{s}{d}$ = strain on a unit of fibers at a distance unity.

$\frac{s}{d}y$ = strain on a unit of fibers at a distance $y$.

$\frac{s}{d}y\delta$ = strain on an element of fibers at a distance $y$.

$\left(\frac{s}{d}y\delta\right)y$ = moment of strain on an element of fibers at a distance $y$.

Fig. 21




This expression, taken for all values of $y$ within the section, will give the moment of strain of the given section. Let M represent this moment. Then

$$M=\Sigma\left(\frac{S}{d}y\delta\right)y=\Sigma\frac{s}{d}y^2\delta=\frac{s}{d}\Sigma y^2\delta \qquad (34)$$

In (34) the factor $\Sigma y^2\delta$ is called the moment of inertia of the cross section and is represented by I. It is obtained by multiplying each elementary area by the square of its distance from the neutral axis and taking the sum of the products. Representing $\Sigma y^2\delta$ by I, we have,

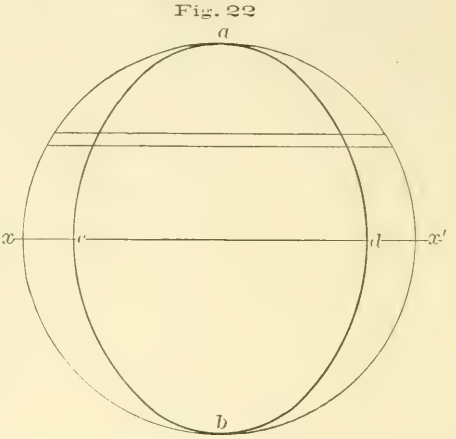
$$M=\frac{S}{d}I \qquad (35)$$

We must not, however, suppose that the moment of resistance involves the product of the strains on the different parts of the cross section into the *squares* of their distances from the neutral axis. The moment of resistance is obtained by multiplying each elementary strain $\left(\frac{s}{d}y\delta\right)$ by its distance from the axis ($y$). The $y^2$ in eq. (34) comes from the factor $y$ in the factor of *strain* and the $y$ which expresses the *distance* from the axis.

When S=1, we have $M_1=\frac{I}{d}$ (36)

The quantity $\frac{I}{d}$, that is, the moment of inertia of the surface, divided by the distance of the furthermost fiber from the neutral axis, might with entire propriety be called the unit moment of resistance; for it does represent the moment of resistance of the section corresponding to

Fig. 22




a unit of strain upon a unit of area of fibers most remote from the neutral axis. Since, however, $s$ varies with the nature and quality of the material, while $\frac{I}{d}$ depends only upon the area and form of section, the quantity represented by $\frac{I}{d}$ can be conveniently tabulated while that represented by $s\frac{I}{d}$ cannot so well be. The quantity $\frac{I}{d}$ is, therefore, frequently called the moment of resistance, though $s\frac{I}{d}$ is the real moment of resistance.

The strain upon a unit of fibers most remote from the neutral axis and represented by $s$, is called the "modulus of strain," or "maximum fiber strain." We may frequently refer to either $\frac{I}{d}$ or $s\frac{I}{d}$ as the moment of resistance or simply resistance, since this will lead to no confusion.

To find the moment of resistance of the triangle $abc$ about an axis $mn$ passing through the vertex $c$ and parallel to $ab$.

Let $ab=b$ and $bc=$the altitude of the triangle$=d$.

Draw $af$ and $bg$, each equal to unity, perpendicular to the plane $abc$.

It is plain that the total strain upon the triangle is represented by the volume of the pyramid $abfg-c$, which is equal to $ab\times bg\times\frac{1}{3}bc=\frac{1}{6}bd$; and that the moment of resistance is represented by the static moment of the pyramid. The center of gravity of the pyramid is at a distance from $mn$ equal to $\frac{3}{4}d$. Hence the moment of resistance is equal to

$$M=\tfrac{1}{6}bd\times\tfrac{3}{4}d=\tfrac{1}{8}bd^2 \qquad (37)$$

Fig. 23

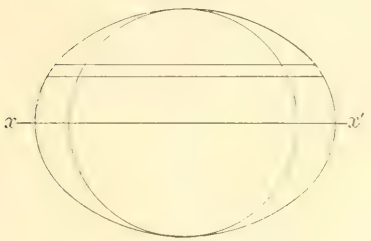
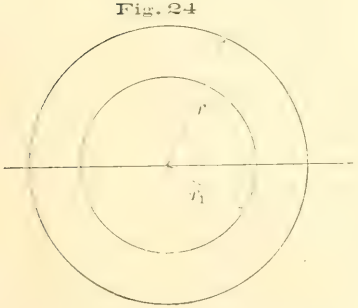



Fig. 24




To find the moment of resistance of a triangle ABC (Fig. 17) about an axis coinciding with the base; we observe that the moment of resistance of this triangle is equal to that of the parallelogram ABCD less that of the triangle ABD. Hence, from eqs. (3) and (37)

$$M_1=\tfrac{1}{3}bd^2-\tfrac{1}{8}bd^2=\tfrac{1}{12}bd^2 \qquad (38)$$

To find the resistance of a triangle having angles at 45° at A and C, and therefore 90° at B.

We have $d=\frac{1}{2}b$ or $d^2=\frac{1}{4}b^2$, and hence

$$M_1=\tfrac{1}{12}bd^2=\tfrac{1}{48}b^3.$$

If BC$=h$, $b^2=2h^2$ and $b^3=2.828\,h^3$, and, therefore,

$$M_1=\tfrac{1}{48}.2.828\,h^3=.059\,h^3=.06h^3,$$

very nearly. (39)

To find the resistance of a square, whose side is $h$, about a diagonal from (39), we have,

$$M_1=.118\,h^3=.12\,h^3, \text{ nearly.} \qquad (40)$$

To find the moment of resistance of a triangle about an axis through the center of gravity. Drop the perpendiculars EF and DH upon the base. Observe that DE$=\frac{2}{3}b$, AF$+$CH$=\frac{1}{3}b$; the altitude of BED$=\frac{2}{3}d$ and EF$=\frac{1}{3}d$. Also that the strain along the line AC is only half as much as at the point B. Hence the moment of resistance of

Fig. 25

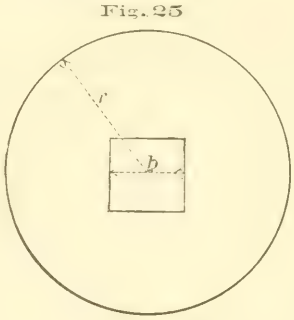
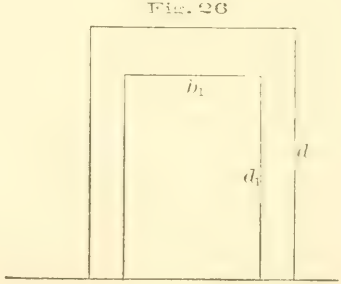



Fig. 26




$$BED=\tfrac{1}{12}(\tfrac{2}{3}b)(\tfrac{2}{3}d)^2\frac{16}{24\times27}bd^2$$

the moment of resistance of

$$EAF\times DHC=\tfrac{1}{2}\text{ of }\tfrac{1}{4}(\tfrac{1}{3}b)(\tfrac{1}{3}d)^2=\frac{3}{24\times27}bd^2$$

and the moment of resistance of

$$EDFH=\tfrac{1}{2}\text{ of }(\tfrac{2}{3}b)(\tfrac{1}{3}d)^2=\frac{8}{24\times27}bd^2$$

Hence the moment of resistance of

$$ABC=M_1=\tfrac{1}{24}bd^2\ldots \qquad (41)$$

Since the equation $M_1=\dfrac{I}{d}$ or $dM_1=I$

is perfectly general, the moment of inertia is equal to the moment of resistance multiplied by the distance from the axis to the outermost fiber; or the moment of resistance is equal to the moment of inertia divided by the same quantity.

To find the polar and plane moments of inertia of a circle.

The polar moment is the moment about an axis through the center perpendicular to its plane.

Fig. 27

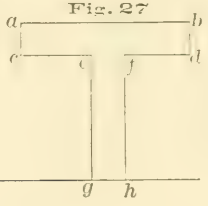
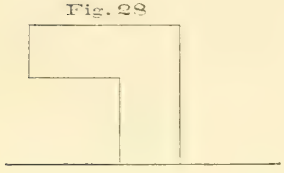



Fig. 28



Let $r$=radius, $y$ and $y+dy$ the radii of two smaller circles concentric with the other. The area of the annulus is, $\delta=2\pi y dy$, and the square of its distance from the center being $y^2$, we have the polar moment of inertia of the circle is,

$$I_p=2\pi\int_0^r y^3dy=\tfrac{1}{2}\pi\delta^4 \qquad (42)$$

Now, considering *any* elementary area, it is plain that its polar moment is equal to the sum of its moments about XX′ and YY′.

The polar moment of the *entire* circle is, therefore, equal to the sum of its moments about XX′ and YY′.

But these latter are evidently equal, and hence either is equal to half the polar moment.

Hence $I=\tfrac{1}{4}\pi r^4$ (43)

The moments of resistance are found, of course, by dividing these expressions by $r$.

Hence $M_p=\tfrac{1}{2}\pi r^3$ (44)

and $M_1=\tfrac{1}{4}\pi r^3$ (45)

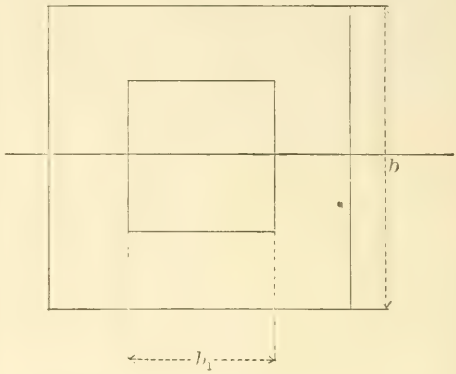
To find the polar moment of resistance directly, we have $\delta=2\pi y dy$ as above. The strain on a unit of area of the outermost fibers of the circle being unity, the strain on a unit of fibers at the distance $y$, is $Y_r$. Hence the strain on the annulus is, $2\pi y dy\,\frac{y}{r}\,y=\frac{2\pi}{r}\,y^3dy$; and the moment of that strain is $\frac{2\pi}{r}y^3dy$. Hence

$$M_p=\frac{2\pi}{r}\int_0^r y^3dy=\frac{2\pi}{r}\cdot\frac{r^4}{4}=\tfrac{1}{2}\pi r^3$$

and $M_1=\tfrac{1}{4}\pi r^3$.

To find the moment of resistance of an ellipse about its shorter axis, $cd$.

Fig. 29




Let $ab=2a$ and $cd=2b$.

Circumscribe a circle about the ellipse. The resistance of the circle is, $\frac{1}{4}\pi r^3=\frac{1}{4}\pi a^3$. But considering *any* elemenary strip parallel to XX′, the length of that strip, included within the ellipse, is to the length included within the circle as $b$ is to $a$. Hence the resistance of the ellipse is

$$M_1=\tfrac{1}{4}\pi a^3\frac{b}{a}=\tfrac{1}{4}\pi a^2b \qquad (46)$$

For an ellipse about its longer axis inscribe a circle. The notation being as before we have for the circle

$$M_1=\tfrac{1}{4}\pi b^3,$$

and, therefore, for the ellipse,

$$M_1=\tfrac{1}{4}\pi b^3\frac{a}{b}=\tfrac{1}{4}\pi b^2a \qquad (47)$$

A hollow circle (Fig. 24) or annulus. To find the moment of resistance of a section equal to the hollow, we observe that the resistance on the outer limit of the hollow is not unity, but only $\frac{r_1}{r}$. Hence the moment of resistance by (45) is

$$\tfrac{1}{4}\pi r_1^3 \times \frac{r_1}{r} = \frac{\tfrac{1}{4}\pi r_1^4}{r} \qquad (48)$$

That is, the moment of resistance of the hollow is equal to its moment of inertia divided by the distance of the axis from the farthest fiber of the whole section. Hence by (45) and (48) the moment of resistance of the whole section is

$$M_1 = \tfrac{1}{4}\pi r^3 - \frac{\tfrac{1}{4}\pi r_1^4}{r} = \frac{\tfrac{1}{4}\pi r^4 - \tfrac{1}{4}\pi r_1^4}{r} \qquad (49)$$

Hence the moment of resistance of a hollow section is equal to the difference of the moments of resistance of the whole section and that of the hollow; or it is equal to the difference of the moments of inertia of the same sections divided by the distance from the axis to the farthest fiber.

The moment of resistance of the section shown in Fig. 25, for example, is,

$$M_1 = \tfrac{1}{4}\pi r^3 - \frac{1\tfrac{1}{2}b^4}{r} = \frac{\tfrac{1}{4}\pi r^4 - 1\tfrac{1}{2}b^4}{r} \qquad (50)$$

Moment of resistance of a hollow rectangle.

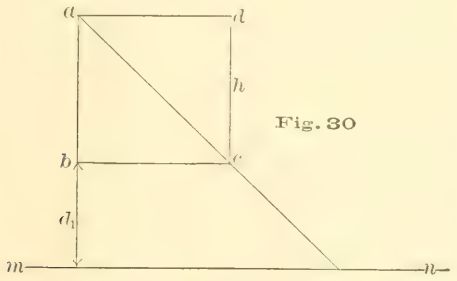


Fig. 30

Eq. (3) gives the moment of resistance of the whole section $= M' = \tfrac{1}{6}bd^2$.

The strain at $b_1$ is equal to $\frac{d_1}{d}$, therefore for the hollow

$$m'' = \tfrac{1}{6}\frac{d_1}{d}b_1 d_1^2 = \tfrac{1}{6}\frac{b_1 d_1^3}{d}.$$

Hence for the real section

$$m = m' - m'' = \tfrac{1}{6}\frac{bd^3 - b_1 d_1^3}{d} \qquad (51)$$

Formula (51) evidently applies to the "T" section as shown in Fig. 27 or to the "angle" as shown in Fig. 28.

If $d = \tfrac{1}{2}b$ and $d_1 = \tfrac{1}{2}b_1$, (51) becomes

$$M_1 = 1\tfrac{1}{2}\frac{b^4 - b_1^4}{b}, \qquad (52)$$

Hence for a hollow *square* Fig. 29,

$$M_1 = \tfrac{1}{6}\frac{b^4 - b_1^4}{b}. \qquad (53)$$

If $b_1 = b$, the web vanishes and equation (51) gives for the flange alone,

$$M_1 = \tfrac{1}{3}\frac{b(d^3 - d_1^3)}{d} = b(d - d_1)\frac{d^2 + d_1 d + d_1^2}{3d}$$

$$= b(d - d_1)\frac{3dd_1 + (d - d_1)^2}{3d}$$

$$= b(d - d_1)(d_1 + \frac{(d - d_1)^2}{3d}. \qquad (54)$$

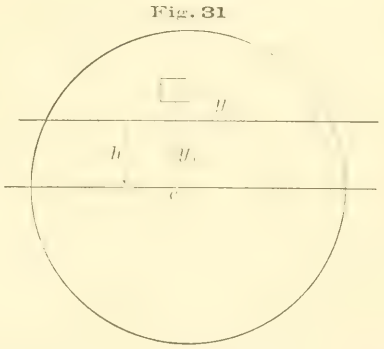
Let $d - d_1 = h$ and $b(d - d_1) = a$ = area of the flange.

Then $M_1 = a\left(d - h + \tfrac{1}{3}\frac{h^2}{d}\right) = a\left(d_1 + \tfrac{1}{3}\frac{h^2}{d}\right)$

$$= a\left\{\frac{(d - \tfrac{1}{2}h)^2}{d} + \frac{h^2}{12d}\right\} \qquad (55)$$

$$= a\frac{(d - \tfrac{1}{2}h)^2}{d} \text{ nearly.} \qquad (56)$$

Fig. 31




In a similar way we find for the triangle

$$abc,\ M = a\left(d - \tfrac{2}{3}h + \frac{h^2}{6d}\right) \qquad (57)$$

and for the triangle $abc$

$$M = a\left(d - \tfrac{4}{3}h + \frac{h^2}{2d}\right) \qquad (58)$$

in which $a =$ the area of the triangle.

From (55) we have the moment of inertia of a rectangle about an axis outside of the section, as shown in Fig. 27,

$$= I = ad\left(d - h + \frac{h^2}{3d}\right) = a\left\{(d - \tfrac{1}{2}h)^2 + \frac{h^2}{12}\right\}$$

$$= a\left\{g^2 + \frac{h^2}{12}\right\} = ar^2 \text{ say} \qquad (59)$$

in which $g = d_1 + \tfrac{1}{2}h =$ the distance from

the neutral axis to the center of gravity of the section.

$r$ is called the radius of gyration, and expresses the distance from the axis to a point, at which, could the whole area of the rectangle be placed, the moment of inertia would not be changed.

Dividing by $a$ and extracting the square root of (59), to two terms, gives

$$v=g+\frac{h^2}{24g} \qquad (60)$$

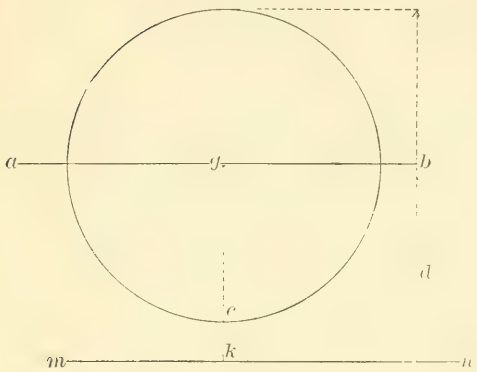
If the axis passes through the center, $g=o$, and (55) gives

$$r=\frac{h}{\sqrt{12}}=.289\,h \qquad (61)$$

If the axis passes through one edge $g=\frac{h}{2}$ and

$$r=\frac{h}{\sqrt{3}}.577\,h \qquad (62)$$

Fig. 32




FORMULAS OF REDUCTION.

To find a general expression for the moments of inertia, I, and of resistance $M_1$, about any axis.

Let $y$=distance of any element from the axis.

$y_0$=the distance of any element from the parallel axis through the center of gravity, and $h$ the distance between the axes.

Let $I_0$=the moment of inertia about the axis through the center of gravity. Let the elementary area be represented by $d$A, A being the area of the section.

Now $\qquad I_0=\int y_0^2 dA, \qquad$ and

$$I=\int y^2 dA=\int(y_0-h)^2 dA=\int y_0^2 dA - \int 2hy_0 dA+\int h^2 dA=I_0+h^2A \qquad (63)$$

Since $\int y_0 dA$, which expresses the sum of the products of all the elements of area into their distances from the axis, is equal to zero.

Again, let $d_0$= the distance of the farthest element from the axis through the center of gravity, and $d$ the similar distance from the parallel axis. Let $M_0$ and $M_1$ represent the moments of resistances about the axis through the center of gravity and the parallel axis.

Now $I=md$ and $I_0=M_0d_0$.

Hence from (63)

$$Md=M_0d_0+Ah^2 \text{ or } M=M_0d_0+\frac{Ah^2}{d} \qquad (64)$$

(64) is the formula of reduction for the moments of resistances.

To find the moment of resistance of a circle about any axis $mn$.

Let $r$= radius, $a$= the area of the circle and $g$, $d_1$ and $d$ as before.

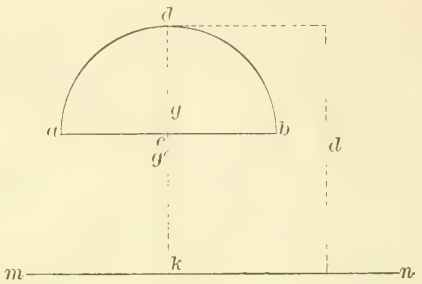



Fig. 33

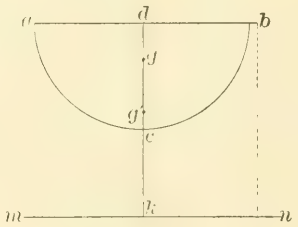



Fig. 34

Let $I_0$= the moment of inertia about $ab$ and I= the moment of inertia about $mn$.

Now $\qquad I_0=\frac{1}{4}\pi r^4=\frac{1}{4}ar^2$.

$$I=I_0+ag^2=a[(d-r)^2+\frac{r^2}{4}]$$
$$=a(d^2-2dr+\tfrac{5}{4}r^2)$$
$$\therefore\ m=\frac{I}{d}=a\left(d-2r+\frac{5r^2}{4d}\right)=a\left(d_1+\frac{5r^2}{4d}\right) \qquad (65)$$

Putting $2r=h$, (65) becomes

$$M=a\left(d-h+\tfrac{5}{16}\frac{h^2}{d}\right)=a\left(d_1+\tfrac{5}{16}\frac{h^2}{d}\right) \quad (66)$$

To find the moment of resistance of an ellipse about any axis, parallel to a diameter of the ellipse.

Let $2b$ and $2r$ represent the axes, $r>b$, and suppose $r$ perpendicular to the axis of moments. Then, in the same way as for the circle we deduce

$$m=a\left(d-2r+\tfrac{5}{4}\frac{r^2}{d}\right)=a\left(d_1+\tfrac{5}{4}\frac{r^2}{d}\right)$$
$$=a\left(d_1+\tfrac{5}{16}\frac{h^2}{d}\right) \quad (67)$$

This shows that the center of moments of an ellipse is the same as of a circle whose diameter coincides with the axis of the ellipse, which is perpendicular to the axis of moments.

A semi-circle (Fig. 33).

Let $r$=radius, $a$=area, and let $g$ be the center of gravity.

Let I, $I_1$ and $I_0$ represent the moments of inertia about $mn$, $ab$ and an axis through $g$ parallel to $ab$ or $mn$.

From Mechanics we have $cg=.424r$

Now $I_1=\frac{\pi}{8}r^4$

$$\therefore I_0=\frac{\pi}{8}r^4-\frac{\pi}{2}r^2cg^2=\frac{\pi}{8}r^4-.09\pi r^4$$
$$=.035\pi r^4=.11r^4 \text{ very nearly.}$$

Hence

$$I=.035\pi r^4+\frac{\pi}{2}r^2\times gk^2=.035\pi r^4+$$
$$\frac{\pi}{2}r^2(d-.576r)^2=.20\pi r^4+\frac{\pi}{2}r^2(d^2-1.15dr)$$

Therefore $$M=\frac{\pi}{2}r^2\left(.40\frac{r^2}{d}+d-1.15r\right)$$
$$=a\left(d-1.15r+\frac{2r^2}{5d}\right) \quad (68)$$

Putting $h=2dg=dg'=1.15r$, this becomes, $$m=a\left(d-h+\frac{3}{10}h^2\right) \quad (69)$$

A semicircle Fig. 34.

We have $I_0=.035\pi r^4$

and $$I=.035\pi r^4+\frac{\pi}{2}r^2gk^2$$
$$=.035\pi r^4+\frac{\pi}{2}r^2(d-.424r)^2$$
$$=\frac{\pi r^4}{8}+\frac{\pi}{2}r^2(d^2-.848dr)$$
$$\therefore m=\frac{\pi}{2}r^2\left(d-.848r+\frac{r^2}{4d}\right) \quad (70)$$

Putting $h=2dg=dg'=.848r$ we have
$$m=a\left(d-h+\frac{1.04h^2}{3d}\right) \quad (71)$$

Thus we see that for the same values of $d$ and $h$, (or of $d$ and $g$, since $g=d-\frac{1}{2}h$) the lever arms of all these sections are very nearly the same, since the terms

$$\tfrac{1}{3}\frac{h_2}{d},\ \tfrac{5}{16}\frac{h_2}{d},\ \tfrac{2}{5}\frac{h_2}{d} \text{ etc.}$$

are approximately the same

We observe, too, that since the terms are quite small, the lever arm is in all cases, approximately, as much less than the distance to center of gravity of the section as this distance is less than the distance to the farthest fiber of the section.

From (55), $M_1-ad_1=\frac{ah^2}{3d}$, or $m-a\left(g-\frac{h}{2}\right)$
$$=a\frac{h^2}{3d} \text{ or } ag-m_1=a\left(\frac{h}{2}-\frac{h^2}{3d}\right)$$

But $m_1-ad_1$=the difference between $ad_1$ and the true moment $m_1$, or the error of $ad_1$ and $ag-m_1$ shows the errror of $ag$.

Now $$\frac{ag-m_1}{m_1-ad_1}=\left(\tfrac{1}{2}-\frac{h}{3d}\right)\div\frac{h}{3d}=\frac{3d}{2h}-1 \quad (72)$$

Since $d$ is usually several times larger than $h$, (72) shows that $ag$ differs from the true moment several times as much as $ad_1$ differs; yet $ag$ is the value generally taken for $m_1$, instead of the equally simple and more accurate value $ad_1$.

It is plain that if each unit of area was strained equal to unity, the total strain would be equal to the area $a$, and the moment of strain would be equal to $ag$; but the outermost fibers only are so strained, and as the strain decreases uniformly toward the axis, the total strain is consequently much less than $a$ (though the lever arm is indeed a little greater than $g$) and the moment of strain, or resistance, is much less than $ag$, as we have shown.

We may suppose, however, the strain equal to the area, which is *greater* than the real strain, provided we use a lever arm correspondingly *less* than the real

lever arm. This is what the equations do, and they may be so interpreted and understood. The lever arm, by which the area is multiplied, may be called the reduced lever arm.

The important and practical principle to be remembered is this: that the lever arm of the moment extends from the axis to a point quite as far inside of the center of gravity as the center of gravity is inside of the outermost fiber.

## ENGINEERING NOTES.

ON THE INFLUENCE OF THE ADDITION OF VARIOUS PULVERIZED SUBSTANCES TO PORTLAND CEMENT—BY DR. BÖHME—Three series of researches were undertaken A. Researches with a pure cement, and its mortar formed with two kinds of sand mixed with seven different substances. B. Researches with cement mortars of thirty-nine different cements, with and without an addition of slag. C. Researches with cement mortars with an addition of slag and gypsum.

A. A Portland cement of average quality having been selected, it was tested for tension and compression, as pure cement, as mortar of one part cement, three parts standard sand, and as mortar of one part pure cement, three parts Berlin sand. Tests were made at seven, twenty-eight, ninety, and three hundred and sixty-five days. Corresponding tests were made with neat cement and cement-mortar briquettes in which 10, 20, or 50 per cent. of the cement was replaced by the following substances: (1) finest cement; (2) finest sand; (3) Duisburg slag; (4) Upper Silesian slag; (5) trass; (6) brick powder; (7) limestone powder.

The addition of (1) diminished the tensile strength of pure cement, but increased that of the cement mortars. For all the other additions the tenacity both of cement and cement-mortars is diminished.

As to the compression tests, the cubes of pure cement and pure cement with the additions give results similar to those for tension. But the strength of the cubes of cement-mortar with the additions is sometimes equal and sometimes greater than that of those without the additions.

B. To try if the same conclusion would hold good with other cements, thirty-nine German cements were selected and tested as pure standard cement-mortar without additional material, and also with an addition of 20 per cent. of Duisburg slag. Of these, twenty-nine cements showed the greater tensile strength in all stages of hardening when without any additional material. The cements with 20 per cent. addition of slag lost nearly that proportion of strength.

C. Two cements were tried in the following ways: ($\alpha$) 100 parts cement, 300 parts standard sand; ($\beta$) 90 parts cement, 10 parts slag, 300 parts sand; ($\gamma$) 90 parts cement, 8 parts slag, 2 parts gypsum, 300 parts sand. In all stages of hardening $\beta$ was weaker than $\alpha$; but at twenty-eight days $\gamma$ was about as strong as $\alpha$, and at ninety days it was stronger. The increased strength, however, is known to be obtained at the cost of trustworthiness—*Abstracts of the Institution of Civil Engineers.*

THE WATER-SUPPLY OF ANTWERP DURING THE SUMMER OF 1885—The long continued drought of the summer of 1885, and the sudden increase in the consumption of water caused by the International Exhibition, had the effect of preventing the purifying-apparatus from completely destroying the marshy taste and smell which characterizes the water of the Nethe.

The dread of cholera, which at that time was ravaging Spain, rendered the inhabitants of Antwerp anxious as to the wholesomeness of the water-supply, and caused the Town Council to appoint a commission of five chemists, with Mr. C. Angenot, chemist to the city of Antwerp at their head, to institute a searching investigation into the whole subject.

The report, which was published on the 30th November, treats successively of the choice of a source of supply, of the quality of the waters of the Nethe, of the process of purification and its theory, of the general arrangement of the works, of the quality of the water furnished during the dry season of last summer, of the cause of the marshy taste and smell, of the present quality of the water-supply, and finally, of the examination of the water with reference to microbes and bacteria.

The general conclusions arrived at are, that the water supplied by the water company was never unwholesome, that the cause of the taste and smell, which only lasted for a short time, was the exceptional demand for water coinciding with an abnormally bad condition of the river caused by the prolonged drought, and that all doubts of the efficacy of the purification of water by means of iron applied through the instrumentality of the revolving purifers must fall before the researches of the English scientific men who have investigated the subject, and before the labors of the commission which has confirmed their conclusions to the fullest extent

A further report is promised, in which the investigations into the microbe and bacterial life will be more fully discussed—*Abstracts of the Institution of Civil Engineers.*

THE DESTRUCTIVE ACTION OF CEMENT-MORTAR UPON LEAD PIPING—BY OTTO PESCHKE, of Berlin—Owing to a communication from an engineer at Hanover, the author forwarded a sample of lead pipe, which had served for about six years as the supply-pipe to a fountain basin, to Dr. v. Knorre at the chemical laboratory of the Berlin Polytechnic for analysis. This pipe, throughout the portion of its length which was imbedded in the cement, was powerfully corroded; the corrosion being most marked at the end of the pipe next the basin, and the effect diminishing as the pipe receded from the water. The pipe was coated with a chocolate-colored layer of oxide of lead, of the hardness of glass, which adhered strongly to the metal. A portion of the brownish mass, at that part where it was the thickest, was detached from the pipe, pounded in an agate mortar, dried at 110° Centigrade, and

submitted to chemical analysis. It contained 99.05 parts of oxide of lead, the residue consisting of carbonic acid, with traces of lime and silica, which latter may have been due to small quantities of cement adhering to the outer surface of the pipe Dry Portland and Roman cements have been found by the author to have no action upon lead, but the presence of water appears necessary to effect corrosion. The author invites the attention of engineers and chemists to this action, which is difficult to explain, and which may be due to certain phenomena in connection with the induration of cement mortar which are at present extremely obscure—*Gesundh its-Ingenieur.*

The Asphalt Pavements of Berlin—By Léon Malo—In 1876, when the maintenance of the public ways of Berlin passed from the hands of the State into those of the local authorities, there were in that city, 4,476,000 square yards of way; of which 14,400 square yards were of stone pavement laid on sand, in good condition, with 4,018 yards of the same in bad condition; 432 000 yards of macadam, and 12,000 yards of asphalt. At present there are 450,000 square yards of stone pavement laid on a solid foundation, and jointed with sand and bitumen; 654,000 yards of pavement laid on gravel, in quiet streets, in good condition; 3,705,600 yards of pavement in bad condition, temporarily laid, 579,600 yards of macadam, principally in outlying quarters, and in the Zoological Gardens; 384,000 yards of asphalt, and 48,000 yards of wood pavement

Ordinary stone pavements are laid in Swedish granite (Karlskrona), except some thousands of yards laid in porphyry from Belgium. The blocks are delivered ready for laying, the granites being from 7½ inches to 8 inches in thickness; and the porphyries from 6 inches to 6½ inches thick. According to the usual method of laying, a 4-inch layer of broken granite is deposited on the sub-soil, and upon this a second bed of granite more finely divided, also 4 inches thick, which is rolled down under a 15-ton steam-roller. A layer of gravel, about 1 inch thick, is scattered over the rolled bed, on which paving stones or sets are placed half an inch clear of each other; jointed in the intervals with a mixture of pitch and creosote. Under the lines of tramway, whatever may be the superstructure, a foundation of cement-concrete is made. Paving consisting of stone-sets laid on concrete is not in favor in Berlin.

Wood pavement, of Swedish fir, was first tried on a large scale in Berlin in 1879, laid by the Improved Wood Pavement Company. It has since disappeared, probably for the same reason that the pavement laid in Paris by the same company was removed after having been down for five years. Though this pavement was laid on a thick bed of cement-concrete, in a street of light traffic, near the Opera, the wood decayed, it wore very unequally, and was converted into mire. Carriages ceased to use the street, in order to avoid excessive jolting. Wood pavements laid by other companies still exist, to the extent of 48,000 square yards, in Berlin; but it is very unpopular, in consequence of the odor of the melted tar which escapes from the joints in summer, and its removal is but a question of time.

Asphalt pavement is extensively laid in Berlin, 384,000 square yards being covered with it, and it is destined to supersede other pavements in all the best streets of that capital. Four different asphalts are used, Val-de-Travers, Seyssel, Ragusa (Sicily), and Limmer (Hanover). The Val-de-Travers asphalt, the first that was laid, tends to become softened in the height of summer under the wheels of carriages, and to form waves, which nevertheless disappear on the return of cooler weather. In Paris, a mixture of Seyssel asphalt with that of the Val-de-Travers is found to resist that tendency. Ragusa asphalt is open to the same objection; but the Seyssel asphalt, holding a less percentage of bitumen in its composition, is entirely free from softening. It is more difficult to manipulate than the two others, and requires to be very regularly heated for laying; but it is harder and much more durable than these. The concrete foundation, which is from 8 inches to 9 inches in thickness, is laid with extreme care. It is made with an allowance of about 290 lbs. of best Portland cement for each cubic yard of "ballast," procured in the neighborhood of Berlin, consisting of flint stones mixed with a kind of corse sand. The asphalt is never laid until the concrete is perfectly set and completely dry—a precaution of prime importance for obviating the formation of steam and the consequent degradation of the asphalt, heated as it is to upwards of 250° Fahrenheit, which takes place when that precaution is not observed, as has been noticed in the earlier attempts of the Parisians in laying asphalt pavements—*Abstract from the Institution of Civil Engineers.*

## IRON AND STEEL NOTES.

Tinned Iron—A writer in *Industries* makes the following observations upon the subject of the regeneration of tinned iron. After describing the precautions necessary in the acid process, he proceeds:—"Persons in the trade say that the metal is injured by absorption of the acid, and affirm that occasionally it is necessary to repeat the annealing in order to remove rottenness engendered in this manner. To the writer it appears more probable that the effect is due to occlusion of hydrogen, for the iron can scarcely be porous enough to absorb the liquid, while the power of occluding gases is a well known property of iron and some other metals. If a piece of sheet iron be immersed for some time in hydrochloric (muriatic) acid, and then be well rinsed in a stream of water for half a minute, and the acid thus removed from the surface, careful observation will reveal an interesting phenomenon. For some time after the washing, minute bubles may be seen bursting through the film of water left upon the iron, and the sound of effervescence may be heard if the metal be held near the ear. This is probably due, not to any evolution of hydrogen by acid, since this has been removed by washing, but to the escape of hydrogen from the pores of the iron. Producers of wrought iron say that the scrap stripped by acid always makes

inferior iron if mixed in any considerable proportion with new metal. Yet this tin plate is rolled originally from good iron, and can be made so again if suitably treated. The reason, doubtless, is to be sought, not in the imperfect removal of tin, as often stated, but in the occlusion of hydrogen gas." If this view be correct it is probable that the hydrogen could most speedily be removed in an electrolytic bath, containing a suitable oxidising agent in which the iron was made the positive electrode.

ON A PECULIAR ACTION IN STEEL PROPELLER SHAFTS—At a recent meeting of the Institution of Engineers and Shipbuilders in Scotland, Mr. Thomas Davison directed the attention of the members to what he considered a peculiar form of corrosion in propeller shafts. He distinguished it from the ordinary form of corrosion, which has long been observed to take place at the ends of the covering brasses of propeller shafts, and which frequently causes a groove so deep as to render them unfit for use. He gave it the name of "radial corrosion," as it resembles a crack round the shaft extending towards the center, the corroded part usually having a radiated crystalline appearance quite different, in his opinion, from any fracture produced by mechanical force. Having in the course of his experience met with many failures of iron shafts, he was induced, from not having had a single case of failure in the use of steel, in steel ships, steel boilers, steel shafting, piston rods, and other parts of engines, to advise the use of steel shafts made from one ingot, so as to avoid the flaws and imperfections inseparable from iron shafts made of many pieces welded together. He was disappointed, however, to find that this special kind of corrosion of which he spoke, interfered with the use of steel in propeller shafts, and in some cases they were so rapidly corroded that the steel shafts had to be replaced by iron ones until he had time to test the causes of the failure.

As some of his friends did not agree with Mr. Davidson in thinking that the flaws in the shafts were caused by corrosion, he wished to give his reasons for his opinion. The shafts which had failed were all of the usual size of iron shafts; their material, as tested by Kirkaldy, was found to have an elastic limit and ultimate strength of over forty per cent. more than iron; and when tested after corrosion were found not to have deteriorated. Moreover, it was found that of two shafts exactly similar, one corroded and the other remained perfectly sound, and he inferred that the one was water-tight and the other was not. He illustrated the flaws by many drawings and spicimens from shafts, and concluded by urging on engineers the necessity for paying special attention to the subject, so that a remedy might be found for what seems to be the only objection to the use of steel for propeller shafts.

In the discussion which followed the reading of the paper, opinion was divided on the subject, some agreeing with Mr. Davison that the failure of the shafts was caused by corrosion, others thinking it was caused by the want of stiffness in the steel. The propellers being overhung, their weight and also their reaction would cause a continual bending and unbending, which, combined with rotation, would rapidly produce the action described by Mr. Davison. Mr. Dick, of the Steel Company of Scotland, had conducted some experiments with rotating pieces of steel subjected to bending action, and he had found that fractures very similar to those described by Mr Davison were produced. We will not pronounce an opinion on the subject; but as it is one of considerable importance both to steel makers and marine engineers, we will be glad to have the opinions of a few correspondents, that thus we may assist in the attainment of the object Mr. Davison had in view when preparing his paper —that is, the determination of the real causes of the flaws in the shafts.—*Industries.*

## RAILWAY NOTES.

NOTES ON THE PERMANENT WAY OF LIGHT RAILWAYS—By J. W. POST, Engineer to the Netherlands State Railways Company—The first concession for light railways on the 1.5 meter gauge, given under the law of 9th August, 1878, by the Dutch Government, was to the Geldersche-Overysselsche Company, for lines of a total length of 135 kilometers. The author describes the system of permanent way adopted for this railway, constructed under his superintendence. At present steel rails and red pine sleepers, 1 meter apart, are used, but it is intended to replace the wooden by metallic sleepers. The rails are of the Vignoles type: height, 120 millimeters; width of bottom flange, 90 millimeters; sectional area, 32.6 square centimeters; and weight, 25.6 kilograms per meter length. The standard length of rail is 9 meters. The price paid for rails between 1882 and 1887 was 70.62 florins per ton of 1,000 kilograms, or £5 8*s.* 6*d.* The fishplates are steel, the outside plate with an angle bent outwards, to stiffen the joint, rests on two sleepers. To prevent the rails from creeping, a dogspike is driven at each end against this flange.

The same price per ton was paid for the fishplates as for the rails. Grover spring-washers, of cast steel, are used wtih all bolts. These only cost 11 florins per thousand. The total weight of metal per lineal meter of permanent way is 55.6 kilograms. At the points the rails are placed vertical; the outer rails are not lifted in the curves. The maximum widening of guage in the curves is of 20 millimeters. The angle of crossing is 1 in 9 in all cases, and the total length of a set of points and crossings is 24.01 meters. The points can therefore be laid on the existing tract without cutting up the rails. The switches are shaped to a curve of 180 meters radius, and only 7.50 meters long, and carefully planed to exact shape. No part is longer than 6 meters, to facilitate carriage. The crossings are of a total length of 2.16 meters, and joined to the rails at each end by straight fishplates. The packing-pieces between abutting rails are specially cast for each end. The grooves are 44 millimeters wide, and 42.5 millimeters deep. The check-rails are 3 meters long. The points and crossings are laid on oak sleepers of 14 by 25 centimeters,

and 55 centimeters apart. The cost per kilometer of permanent way, without ballast or laying, is 6,000 florins, and that for a complete set of points and crossings is 575 florins. The paper is accompanied by several addenda and drawings.—*Abstracts of the Institution of Civil Engineers.*

RAILWAYS OF EUROPE IN 1884.—The total length of railways opened for traffic at the end of the year 1883 amounted to 113,716 miles. At the end of 1884 the length open was 117,653 miles, showing an increase of 3,937 miles opened in the course of 1884, or 3.46 per cent. of the total length at the end of 1883. The following table shows the length of railways open, in each European State, at the end of 1884:

*Railways of Europe* 1884.

| Designation of State. | Length of Railways open for Traffic at the end of 1884. | Increase per cent. in 1884, above the length of open at the end of 1883. |
|---|---|---|
| | Miles. | Per cent |
| 1. Germany | 22,830 | 2.31 |
| 2. Austria-Hungary | 13,736 | 5.99 |
| 3. Belgium | 2,684 | 1.08 |
| 4. Denmark | 1,208 | 7.23 |
| 5. Spain | 5,383 | 4.99 |
| 6. France | 19,397 | 5.05 |
| 7. Great Britain and Ireland | 18,962 | 1.11 |
| 8. Greece | 109 | 695.45 |
| 9. Italy | 6,167 | 4.97 |
| 10. Low Countries and Luxemburg | 1,649 | 5.28 |
| 11. Portugal | 949 | 2.21 |
| 12. Roumania | 995 | 5.39 |
| 13. Russia and Finland | 15,778 | 2.02 |
| 14. Servia | 152 | .... |
| 15. Sweden and Norway | 5,072 | 2.54 |
| 16. Switzerland | 1,716 | 0.40 |
| 17. Turkey, Bulgaria, and Roumelia | 866 | .... |
| Total | 117,653 | 3.46 |

Of the total increase of length of railway opened in the course of 1884—namely, 3,937 miles—515 miles were opened in Germany, 776 miles in Austria-Hungary, 256 miles in Spain, 933 miles in France, 208 miles in Great Britain and Ireland, 292 miles in Italy, 313 miles in Russia and Finland, 152 miles in Servia, and 125 miles in Sweden and Norway.—*Abstracts of the Institution of Civil Engineers.*

THE TRANSCASPIAN RAILWAY.—A correspondent writing from Askabad to the *Ruski Viedomost* (Russian Gazette) says:—"The construction of the Transcaspian Railway is progressing rapidly towards completion. The embankment is nearly ready all the way to Merv, and the rails are already laid down to Kaakhee, a point about 30 versts distant from the future station of Dooshck, so that everything is ready for opening 560 versts of line. The carriage of material and the means for its transport are both on an extensive scale, and it is hoped that circulation will be possible up to Merv from June 1. At the present moment great activity is being shown in the construction of the bridge over the river Tendghen, which work has been partially delayed through the peculiarly unfavorable nature of the ground forming the bed of the river, in consequence of which it has been necessary to sink into it five rows of cast-iron piles, each pile being 63 feet in length. At Askabad itself, the future centre of the Transcaspian railway system, the buildings in connection with the railway are rapidly rising.

## ORDNANCE AND NAVAL.

IN March the obsolete French armor-clad Armide was towed to sea in the Juan Gulf and allowed to drift. The Colbert, Admiral Duperré, Friedland, Dévastation, Redoubtable, and Suffren, of the French Mediterranean squadron, then steamed about, firing at her at ranges of 3000, 4000, and 5000 meters, with 24, 27, and 32 centimeter guns—roughly 9½in., 11in., and 12in. In time the hull resembled a cullender. Three shots had passed through the armor at the water-line, and would have sunk the ship if she had not been filled with casks. The Armide was then towed into harbor, and the effects of the fire carefully inquired into. This probably is the first occasion in which an armor-clad has been used as a moving target by ships firing when under way.

RUSSIAN IRONCLADS—A St. Petersburg correspondent writes respecting the recent launching of two Russian ironclads by the Czar: "It is interesting to note the great progress made by the Russian Navy during the last three years, no less than twenty-seven vessels of various kinds—exclusive of torpedo-boats—including the two just launched, the Tschesme and Catherine II., having been added to it, whilst several more are on the stocks, among which the great ironclads Sinope, sister ship to the Tschesme, and Imperator Alexander II., and Admiral Nachimoff. There are besides, building, three formidable first-class gunboats, in Sweden, Norway, and Denmark, which are to be delivered this year, whilst it is the intention of the Government to lay down the keel for several others in the Black and Siberian Seas. Great improvements are also being made in the two naval stations, Cronstadt and Sebastopol. In the former place granite quays and breakwaters are being constructed, whilst at Sebastopol the two naval docks recently inspected by the Czar, and which were destroyed in the Crimean War, are so far completed that they will be opened for use this year. The cost of each of these will be £300,000, and the Russian Admiralty states that they are the first undertaking of the kind in which the actual cost has not exceeded the estimate. The plan which has been before the Admiralty some time, of making Libau a naval port, has

been abandoned, but it has been decided to make it the station of the Baltic fleet. In connection with the name, it may also be mentioned that the Obrichoff Steel-plate Works and the Ishorscic iron-plate foundries have recently been improved and enlarged."

Some important additions will shortly be made to the Swedish Navy by the completion of the first-class torpedo boat Galdr and the first-class gunboat Svea. The former was built at the Royal Dockyard, on the same lines as the torpedo boat Sejd, which was constructed by Messrs. Thorneycroft some years ago, and is stated to be quite equal to the latter in solidity and speed, although considerably cheaper. The length of the vessel is 103ft.; breadth, 11½ft.; whilst she draws only 5ft. of water. The engines, which give her a speed of 20 to 21 knots per hour, are of 425 indicated horse-power. The total cost is £6,000. She will carry light guns, and be armed with Whitehead torpedos. The other vessel—the Svea—is being built at the Lindholmen Engineering Works, at Gothenburg. She will be one of the most formidable vessels in the Swedish Navy, carrying her guns in a turret. She will also be armed with torpedos. Some of the heaviest plates used in the construction of this vessel are from Le Creusot; the rest from Motala. Her engines will be very powerful. In Norway progress is being made in the Royal Dockyards with the building of two first-class torpedo boats and two gunboats of the second-class. A proposal is also being made to build an ironclad of modern type, which would be the first possessed by that country, excepting monitors. In Denmark the Government have decided upon two important additions to the navy, in the shape of an ironclad of the second-class, to be named the Valkyrien, which will be heavily armed, and cost about £160,000, and a fast cruiser of the first-class, costing about £150,000. During the present year an important addition will be made to the navy by the launch of the double-turret ironclad Ivar Hvitfeldts, carrying very heavy ordnance, which has taken three years to construct.

## BOOK NOTICES

PUBLICATIONS RECEIVED.

Papers of the Institution of Civil Engineers. No. 1942. The Separation of Galena and Blende. By Ernest DuBois Lukis, Assoc. M. Inst. C. E

No. 2108. Construction in Earthquake Countries. By John Milne, F. G. S.

No. 2110. Design and Stability of Masonry Dams. By William Bulkeley Coventry, M. Inst. C. E.

No. 2158. Modern Machine Tools. By William Wilson Hulse, M. Inst. C. E.

No. 2168. —— Footpaths. By Henry Percy Boulnois, M. Inst. C. E.

No. 2169. The Effects of Various Liquids on Iron. By David Phillips, M. Inst. C. E.

No. 2171. Coefficients of Discharge in Submerged Weirs of Large Dimensions. By Robert Hunter Rhind, M. Inst C. E.

No. 2176. A Circular Chimney Shaft. By John Markworth Wood, Assoc. M. Inst. C. E.

No. 2181. Maintenance of the Belah and Deepdale Viaducts. By William John Cudworth, Assoc. M. Inst. C. E.

A Method of Designing Screw-Propellers. By Christian Hoeple. Philadelphia: Franklin Institute.

Bulletins of the U. S. Geological Survey. Washington: Government Printing Office.

No. 27 Work Done, the Division of Chemistry and Physics.

No. 28. The Gabbros and Associated Hornblende Rocks occurring near Baltimore, Md.

No. 29. On the Fresh Water Invertebrates of the North American Jurassic.

Pilot Charts of North Atlantic Ocean for August and September. Washington: Hydrographic Office.

Monthly Weather Review for July. Washington: Signal Office.

Directory to the Iron and Steel Works of the United States. Philadelphia: American Iron and Steel Association.

Hand-Book of Mineralogy. Determination, Description and Classification of Minerals found in the United States. Science Series No. 86. By J. C. Foye, A.M., Ph.D. New York: D Van Nostrand. Price, 50 cents.

This author's "Mineral Tables" have been known to mineralogists, and have been found so useful that two editions have become exhausted. The material of the old editions is still retained, but important additions have been made in constructing the present book.

The descriptions of the minerals are in this book expanded into paragraphs, and the work is now as complete a manual of determinative mineralogy as can be found in a pocket-book.

Traité Pratique d'Électricité. Par C. M. Gariel. Second volume. Paris: Octave Doin.

This general treatise upon the applications of Electricity aims to give the reader the entire subject to the latest development.

This new volume deals with late telephonic and telegraphic systems and with indicators, registers and regulators.

The total number of illustrations in the two volumes is 600.

The Surveyor's Guide and Pocket Table-Book. By B. F. Dorr. New York: D. Van Nostrand.

This little book contains much that is needed by land surveyors, and that is not contained in other books bearing similar titles.

Rules for the guidance of beginners are clearly given, and as given by the author have the approval of the Commissioner of the General Land Office.

The hints in relation to local attraction are especially valuable.

The book is of convenient size for the pocket and contains tables of natural sines and tangents to five minutes and a traverse-table to quarter degrees.

PRACTICAL PERSPECTIVE. By ARMAND CASSAGNE. Translated by G. MURRAY WILSON. Paris: A. Fourant.

This is a thoroughly scientific treatise on Perspective, although it requires but a moderate amount of geometry to comprehend it. Unlike other works which afford the same amount of geometrical demonstration, this one is adapted to needs of the artist and of architects' draughtsmen. Shades, shadows and water reflections receive special and full treatment.

The illustrations are numerous but not very good.

TREATISE ON THE THEORY OF THE CONSTRUCTION OF HELICOIDAL OBLIQUE ARCHES. By JOHN L CULLEY, C.E. Science Series No. 87. New York: D. Van Nostrand. Price, 50 cts.

The construction of an oblique arch, even of moderate span, requires a kind of skill that is not demanded in arches of the more common or straight type. The problem is considered a somewhat difficult one.

The solution offered by Mr. Culley is easily comprehended. He says in his preface that he is satisfied that much of the confusion and misunderstanding about the subject have arisen from the fact that authors have failed in presenting the fundamental principles, and he declares that the proper conception of the process of generating helicoidal surfaces will clear away all difficulties.

Chapter I. is devoted to the elucidation of the principle of construction of such surfaces.

The construction is certainly clearly described and is illustrated with excellent figures.

The subject is interesting, especially to engineers, whether they engage in practical problems of this nature or not.

THEORY OF MAGNETIC MEASUREMENTS, WITH AN APPENDIX ON THE METHOD OF LEAST SQUARES. By FRANCIS E. NIPHER, A. M. New York: D. Van Nostrand. Price, $1.00.

Magnetic surveys are peculiar in their character. A special training is required to fit the surveyor for his work, and the few who acquire expertness have been heretofore regarded as a class of scientists who had drifted into their work through some fortuitous circumstances or capabilities rather than engaged in it after a systematic course of training

Electrical and magnetic measurements have of late assumed a new importance, and knowledge of the principles involved is eagerly demanded.

The writer gives such hints and instructions to learners as have been suggested by his own experiences in such surveys.

ANALYSE ELECTROLYTIQUE QUANTITATIVE. Par C. BLAS. Paris: Georges Carre.

The electrolytic method of analysis is based on the decomposition by the electric current of compounds in solution, and the formation of deposits on the electrodes.

It possesses the merit of great simplicity, and it requires less supervision than the chemical method. It has been much practiced of late years, and is being constantly extended to embrace a larger number of compounds.

This work is divided into two parts. The first part treats: 1st, of the apparatus required; 2d, of the electrolytic characters of the metals; and 3d, of the separation of the metals one from the other.

The second part treats of the analysis of minerals and metallurgical products.

Forty-two wood cuts embellish the work.

REPORT ON EUROPEAN DOCK-YARDS. By Naval Constructor PHILIP HICHBORN. Washington: Government Printing Office.

This report gives the results of a tour of observation among the dock-yards of England, Scotland, France and Germany.

The ship-yard appliances and tools receive much attention, and are fully illustrated.

Many plans on large scales of ships and ship-yards embellish the reports.

GEOLOGICAL SURVEY OF NEW JERSEY. Annual Report of the State Geologist for 1885. Trenton: John L. Murphy.

The State Geologist arranges his report under five different heads, viz.:

I. The Geographic including Geodetic and Topographic Surveys.

II. Geological, including Structural and Lithological Geology.

III. Economic Geology, including Mining, Quarrying, Water Supply, Drainage, Agriculture and Forestry.

IV. History of the Geological Surveys of the State and Industrial Interests during their Progress.

V. Miscellaneous Papers.

This report shows, as do the preceding ones, that the work done year by year is with special reference to developing and making known the mineral, agricultural and hydrographic resources of the State. It is a good model for geologists in other States

THE TECHNO-CHEMICAL RECEIPT BOOK.—Containing several thousand Receipts covering the Latest, Most Important, and Most Useful Discoveries in Chemical Technology, and their Practical Application in the Arts and the Industries Edited chiefly from the German of Drs. Winckler, Elsner, Heintze, Mierzinski, Jacobsen, Koller, and Heinzerling, with additions by William T Brannt, Graduate of the Royal Agricultural College of Eldena, Prussia, and William H. Wahl, Ph. D. (Heid), Secretary of the Franklin Institute, Philadelphia. Illustrated by 78 engravings. 496 pp. 12mo. Henry Cary Baird & Co. Price, $2.00.

In this book we have the gleanings of the latest scientific and technecal papers of Germany, carefully edited, with numerous and valuable American additions by Dr. Wahl, whose reputation as a painstaking and careful editor at once gives the work an established place among manuals of this character. It is impossible to give any detailed description of the subjects treated for that would be a simple repetition of the table of contents. We find the information to be both accurate and reliable. It is the latest work of this character that has been published, and as such, contains much that is not elsewhere attainable. The book is supplied with a very complete index, making it possible to turn at once to any subject on which infor-

mation is desired. Numerous illustrations are contained in the text, serving to make clear the descriptions. The book is printed in clear type and on good paper. Indeed, its general make-up reflects much credit on its publishers.

THE SEPARATE SYSTEM OF SEWERAGE. By CADY STALEY AND GEO. S. PIERSON, C. E. New York: D. Van Nostrand. Price, $2.50.

There are two systems of sewerage for towns, one known as the combined and the other as the separate. The combined is that most in use, especially in large cities, its object being the carrying off the storm water as well as the sewage. In order to carry off the heavy waterfall of sudden storms the sewers have to be made very much larger than would be needed for the ordinary demand upon them, hence the cost is enormously increased. The main sewers have to be of large size and of brick, the inequalities of which arrest the impurities of the sewage flowing past and generate sewer gas in great volume. It is almost impracticable to keep them properly flushed, especially in dry seasons, whilst, as our home experience has frequently shown, in case of heavy rain-storms the sewers, large as they are, prove insufficient to carry off the surplus water, the sewers are gorged and the streets converted into lakes or beds of rushing currents. At the same time there are cases, especially in some parts of this city, where surface drainage would not carry off the storm water because of insufficent fall, hence some under-ground drainage system is here necessary.

The separate system is designed to carry off the sewage only, with sufficient water to flush and cleanse the pipes. Having to make provision for what is practically a regular supply, the engineer in determining the size of the pipes has only to take into account the probable increase of population in the district to be sewered and the consequent increased capacity required. The advantages of this system as set forth in the volume are very great, including greater convenience, lessened cost, and superior sanitary provisions. The difference in cost is illustrated in the case of the city of Schenectady, N. Y. The estimated cost of the combined system, similar in its general features to that of Cleveland, was $240,000. The separate system was finally adopted and carried into effect under the design and execution of Professor Staley and Engineer Pierson at a cost of $35,000.

Professor Staley claims for the separate system that its introduction marks an important era in the development of sanitary drainage, recognizing as no other system has the prime importance of an early removal of household and industrial wastes, which are the main factors in soil pollution. That it will best meet the requirements of all large and densely populated cities (economy considered), he does not think probable. But that, under competent advice, it can meet the requirements of house drainage more perfectly in any city than the combined system he insists cannot be denied. It is peculiarly adapted to many of the numerous smaller cities, which have been practically debarred from sewerage by its cost, and to outlying portions of larger ones. Its comparatively small cost permits an early and general extension, and the removal of domestic wastes before the soil has become saturated with them beyond a reasonable hope of purification.

In addition to chapters on sewerage in general and on the different systems of sewerage and drainage, the work contains nine other chapters giving plans of sewerage, information as to calculating the quantity of sewage, the laws of flow in sewers, materials and accessories, specification and contract, construction, flushing and ventilation, house drainage and plumbing, cost and assessments. Twenty plates of illustrations and a large folding map of Schenectady, showing the sewerage system, add to the practical value of the work —*Cleveland Paper.*

## MISCELLANEOUS.

IN his lectures on Petroleum, before the Society of Arts, Mr. Boverton Redwood notes that Gibbon states that, in A. D. 624, the Emperor Heraclius wintered at the mouth of the river Kura, seventy miles south of Baku, and that his "soldiers extinguished the fire, and destroyed the temples of the Magi." Marco Polo, who wrote in the 13th century, is supposed to have referred to the petroleum of Baku when he stated that there was in this neighborhood an abundant spring of oil, not good for food, but good to burn or to anoint camels that had the mange; and he added that the people came from great distances to collect it. As far back as 1436, petroleum found on the shores of Lake Tegernsee, in Bavaria, was employed medicinally under the name of "St. Quirinus's oil." Francesco Ariosto stated that he cured men and animals afflicted with itch with the petroleum which he had discovered in 1460 at Mont Libis, in the Duchy of Modena. Jonas Hanway, in the middle of the 18th century, described the so-called eternal fire at Surakhani as a flame in color and gentleness not unlike a lamp that burns with spirit, only more pure, and sometimes rising to a height of 8ft. when the wind blows.

A USEFUL pamphlet on the "Corrosion of Iron and Steel," written by Mr. T. H. Davis, F.I.C., formerly assistant at the Royal College of Chemistry and School of Mines, London, is being published. The author says that if the air or water which surrounds iron contains carbonic acid, or any free acid in minute quantity, the corrosion increases rapidly, but if a caustic alkali, such as potash, soda, or lime be present, the corrosion ceases altogether while any causticity remains, because oxygen and carbonic acid have greater affinities for these alkalies than for iron. He also points out that a perfect paint for the protection and preservation of iron and steel should be one which has a high mechanical adhesive property, and composed of such materials that are related electro-negatively to iron, mixed with some tenacious fluid vehicle containing little or no oxygen, and not capable of being decomposed by the iron beneath it. This would exclude most oily paints.

A curious phenomenon, the *Scotsman* reports, was witnessed at Stonehaven on Sunday afternoon, May 23rd. At intervals just before and after high tide, without any apparent cause, the water along the coast rose and fell from 10in. to 18in. at a time, the subsidence leaving as much as 15ft. to 18ft. of the beach dry. The disturbance continued for three hours, commencing about half-past 4 o'clock. There was no wind, and the sea was quite smooth, but the water advanced and retired with a speed equal to the run of a large river during a spate, and caused so much commotion in the harbor that the fishermen had to secure their boats with extra moorings to prevent damage being done. Indeed, it is seldom that there is so much commotion in the harbor, even during stormy weather. It is surmised that the phenomenon was due to some eruption or subsidence in the sea bottom.

Artesian tube wells are now being fixed at the following places in London:—For the supply of the flats and offices of the Albert Hall-Mansions, South Kensington, and the Westminster chambers, Victoria street, S. W. The depth to be reached in either case to obtain the required supply will be over 400ft. Ere the chalk beds are reached, thick layers of London clay and Woolwich and Reading beds will have to be penetrated. It is only in recent years that this economical and expeditious system of obtaining large supplies of pure water from deep sources has been so perfected as to almost entirely supersede the old method of sinking dug wells, These artesian wells are protected by an even-sized tube, which is carried from the surface to the chalk beds, and it is absolutely impossible for any of the polluted springs which are found in the upper beds to contaminate the lower ones. Messrs. C. Isler & Co., of Southwark street, have the works in hand.

In their report on the water supplied to London during March, Mr. William Crookes, Dr. William Odling, and Dr. C. Meymott Tidy say: "The condition of the water supplied by the metropolitan companies during the past month was, in all respects, thoroughly satisfactory. With the absolute proportion of organic matter continuously low, not much importance can be attached to varations in its relative proportion from month to month. Still, with the advance of the season, the attendant diminution in the quantity of organic matter present in the water is, as usual, well marked. Thus, while the mean amount of organic carbon in the Thames-derived supply for January was .183 part, the mean amount for February was .172 part, and the mean amount for last month .153 part in 100,000 parts of the water, corresponding to scarcely more than a quarter of a grain per gallon of organic matter, a natural constituent of river water, which, even in larger proportions, there is not, as pointed out by the last Royal Commission on Water Supply, any reason to regard as objectionable."

The following are among the prizes offered this year by the Paris Academy of Sciences:—Geometry: A study of the surfaces admitting all the symmetrical planes of one of the regular polyhedrons—3000f.; Francœur prize, the work most conducive to the progress of the pure and applied mathematical sciences—1000f. Mechanics: Extraordinary prize of 6000f. for any work tending most to increase the efficiency of the French naval forces; Montyon—700f.—invention or improvement of instruments useful to the progress of agriculture, of the mechanical arts or sciences; Plumey—2500f.—improvement of steam engines or any other invention contributing most to the progress of steam navigation; Dalmont—3000f.—the best work by any of the Ingénieurs des Ponts et Chaussées in connection with any section of the Academy. Astronomy: Laland prize—gold medal worth 540f.—for the most interesting observation on work most conducive to the progress of astronomy; Damoiseau—10,000f.—best work on the theory of Jupiter's satellites, discussing the observations and deducing the constants contained in it, especially that which furnishes a direct determination of the velocity of light; Valz—460f.—for the most interesting astronomical observation made during the course of the year. Physics: Grand prize of the mathematical sciences—3000f. for any important improvement in the theory of the application of electricity to the transmission of force. Statistics: A prize of 5000f. for the best work on the statistics of France. Chemistry: Jecker prize—5000f.—for the work most conducive to the progress of organic chemistry. Geology: Vaillant prize, on the influence exercised on earthquakes by the geological constitution of a country by the action of water or of any other physical causes.

At a recent meeting of the Royal Society a paper was read on "The Effect of Change of Temperature on the Internal Friction and Torsional Elasticity of Metals," by Mr. Herbert Tomlinson, B A. The vibration period and the logarithmic decrement were very carefully determined at four different temperatures between 0 deg. C. and 100 deg. C., and that the formulæ were worked out by the method of least squares. These formulæ were given in tables. From a consideration of the tables it may be gathered that: (*d*) The torsional elasticity of all metals is temporarily decreased by rise of temperature between the limits of 0 deg. C. and 100 deg. C., the amount of decrease per degree rise of temperature increasing with the temperature. To this may be added that the percentage decrease of torsional elasticity produced by a given rise of temperature is for most metals about twenty times the corresponding percentage increase of length. (*e*) If we start with a sufficiently low temperature the internal friction of all annealed metals is first temporarily decreased by rise of temperature and afterwards increased. The temperature of minimum internal friction is for most annealed metals between 0 deg. C. and 100 deg. C.; for most hard drawn wire, however, the temperature of minimum internal friction is below 0 deg. C. (*f*) The temporary change, wrought by alteration of temperature in the internal friction of metals, is in most cases enormously greater than the corresponding change in the torsional elasticity.

THE ELASTICITY OF METALS. M. TRESCA, the celebrated Parisian experimentalist, lately published in the *Comptes Rendus* the results of observations made as to the effect of hammering, and the variation of limits of elasticity as regards metals and other substances used for technical purposes. He remarks that it has hitherto been usual, in considering the deformation of solid bodies under the influence of extensile force, to recognize only two definite periods, dependent upon the mechanical properties of the substances in question. These periods are the limit of elasticity, and the point of laceration. According to his own trials, M. Tresca has found it necessary at end of the period where the change of elasticity commences, to recognize a third stage, which may be described as a period of fluidity, and which corresponds with the possibility of a continuous deformation under the constant effect of the same tension. This peculiar condition only occurs in substances of a very extensible or plastic nature, and may be regarded as a characteristic of such substances, as the absence of this condition is noticed in materials that are brittle or not extensible, and which are lacerated or fractured without previous deformation. It is already known that the period of alteration of elasticity is much shorter in hard or hardened steel than in iron.

In the year 1871, M. Tresca proved that steel and iron rails, which had undergone a permanent extension, proved completely elastic up to the limit of the burden which they had already experienced. With certain iron and steel rods the same result was obtained five times in succession, and thus the period of complete elasticity could be gradually prolonged, while the co-efficient of elasticity did not appear to suffer any notable change. By the process of repeated extension, if no hammering takes place, tough substances are rendered brittle.

M. Tresca protests against the expressing of the prolongation of metal bars produced by burdens in the form of a percentage of their length. Such prolongation is, he urges, always specially local, and consequently the same in long and short bars, being limited by the proximity of the point of fracture. The indication of elasticity should, therefore, rather be sought in the diminution of the section of the bars at the point of fracture. This portion of a lacerated bar is further remarkable for the loss of the original state of its material composition. At the point of fracture, the substance has become remarkably condensed, and has almost entirely lost its toughness. The final fracture, therefore, takes place in a brittle zone of the metal, and the same condition can be produced by hammering. If a test bar, which has been extended almost to the point of fracture, be thoroughly heated, it can be still further extended before it breaks, and it is really a fact that by alternate stretching and heating such a bar may be extremely changed in its proportions, as is, for instance, the case in wire drawing.—*Industries.*

EGYPTIAN PETROLEUM. The extensive reports that are appearing in the daily papers from their Cairo correspondents, bear out the original announcement that the petroleum supply at Jebel Zeit is of the most copious character. We have yet to learn, however, the general specific gravity of the oil, and until Mr. Tweddle and the chemists at Antwerp and London, where samples have been sent, have expressed an authoritative opinion, this very important point will remain unsettled. According to one of the earliest telegrams dispatched, the oil had a specific gravity approaching that of the heavy Burmese oil, and was capable of yielding only 8 or 10 per cent. of refined petroleum. As the American crude oil yields 75 per cent. of burning oil, and the Russian petroleum 30 per cent., this implies an inability to compete very seriously with existing oil refiners. Petroleum, however, often varies largely in specific gravity in the same district, and it might be that the original samples, and even those subsequently transmitted to Europe, did not fairly represent the general quality of Egyptian oil. But admitting that the oil is not a copious yielder of the petroleum of commerce, it has, apart from this, not only a great future before it as a lubricant and as fuel, but further may yet benefit by the improvements in lamps which are now being made, rendering them able to burn a heavier refined petroleum than that now in general use. The Defries lamp, for instance, burns successfully oil of a specific gravity of .830, which would allow of a very much larger employment of Egyptian oil for illuminating purposes than the percentage we quoted above. Doubtless this success will be followed by others in the same direction. As an enormous demand is arising for the Defries lamp, and the knowledge of the new oil which is being derived from the variety of uses to which it is being applied, will lead to further improvements. In short, now that the heavy oil regions of Russia, Burmah, and Egypt are coming to the front, the pressure of their cheap and copious supply of refined petroleum, heavier than that in possession of the market, and hitherto practically secluded from it, will impel the public to favor the new article, and this will react in turn beneficially upon Egypt and Burmah. Such a tendency deserves to be encouraged, because the heavier oils which are burnt by the Defries lamp are as safe as colza and other vegetable oils, and the risk of fire and accident is thereby reduced to a minimum. Considering that nearly every week, all the year round, an inquest is held in London on the victims of a lamp explosion, and that the development of the petroleum oil trade implies an increase of risk, it is most satisfactory that not only has the Defries lamp—which even when burning ordinary oil can be upset or blown into without fear of spilling the oil or causing an explosion—come into use precisely when wanted but by burning a safe heavy oil has further increased the immunity of the public from danger, and at the same time given additional value to the petroleum fields of Egypt.

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NOTE.—The Editor respectfully calls the attention of the readers of the magazine to the advertisement on the second page of the cover of this number.

VAN NOSTRAND'S

# ENGINEERING MAGAZINE.

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## NEW PRACTICAL FORMULAS FOR THE RESISTANCE OF SOLID AND BUILT BEAMS, GIRDERS, ETC., WITH NUMEROUS PROBLEMS AND DESIGNS.

By P. H. PHILBRICK, Professor of Civil Engineering, State University of Iowa.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

II.

We will now apply the preceding formulas to the different forms of beams, etc.

EYE BEAMS.

To find the moment of resistance about an axis $mn$, through the center of gravity of the section and parallel to $ab$. The

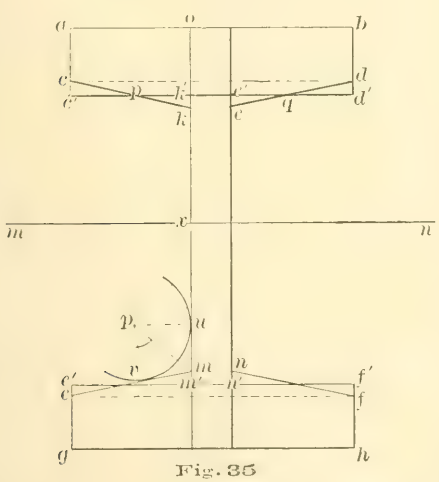


Fig. 35

flanges are usually trapezoidal. We will for the present consider the web as extending through the whole depth of the beam.

Let $abdlnfhgemkc$ represent the eye-beam. Through the middle points, $p$ and $q$, of $ck$ and $ld$, draw the line $c'k'l'd'$; also through the middle points of $em$ and $fn$ draw $e'm'n'f'$. Consider for the present $abd'l'n'f\,hge'm'k'c'$ in place of the original figure.

Let $h'=ac$, the least thickness of the flanges.

$H=ok$, the greatest thickness of the flanges.

$t=kl$, the thickness of the web.

$b=ab-kl=$width of flanges.

$h=\dfrac{H+h'}{2}=$ average thickness of the flanges.

Let $D=ag=$ total depth.

$d=ox=$ one half of total depth.

$D_1=c'e'=$ inside depth of new figure or average depth of original figure.

$d_1=k'x$, one half of the inside depth.

Let $a=$area of each flange$=b\,\dfrac{h'+H}{2}=bh$.

$B=$ area of web $=t.D$.

Now, by number 2 of table 1, the moment of resistance of the web on either side of the axis is $\frac{1}{3}\times\frac{1}{2}B\times\frac{1}{2}D=\frac{1}{12}BD$;

and by (55) the moment of resistance of either flange $=a\left(\frac{1}{2}D_1+\frac{h^2}{\frac{3}{2}D_1}\right)$

Hence the total moment $=m=D_1a+\frac{1}{6}DB+\frac{4ah^2}{3D}$ (73)

or since $a=b\frac{H+h'}{2}$ and $h=\frac{H+h'}{2}$

$$m=D_1a+\tfrac{1}{6}DB+\frac{b}{6D}(H+h)^3 \quad (74)$$

But it is easy to show that the moment of resistance of the new figure exceeds that of the original figure by $\frac{bD_1}{6D}(H+h')^2$

Hence $m=D_1a+\frac{1}{6}DB+\frac{b}{6D}[(H+h)^3 - D_1(H-h)^2]$. (75)

$=D_1a+\frac{1}{6}BD$ very nearly. (76)

Eq. (76) applies at once to built beams, but the flanges are not the same as for solid beams and hence the value of $D_1$ for built beams remains to be pointed out.

With reference to (75), we remark that the quantities within the parentheses are necessarily small, their difference is therefore necessarily small and the factor $\frac{b}{6D}$ being but a small fraction, the product of this by the quantity within the brackets is, in practical cases, but a fraction of a unit—usually a very small fraction.

If in (76) we ignore the web we have,

$$m=D_1a \text{ very nearly} \quad (77)$$

$$\text{or } m=Da \text{ approximately.} \quad (78)$$

Let us now suppose the web to terminate inside the flanges, and let A= the area of a flange, and $b$= the area of the web.

Then we may write $m=AD_1+\frac{1}{6}bD_1$

$=D_1(A+\frac{1}{6}b)$. (79)

The term $AD_1$ is slightly too small for the flange and $\frac{1}{6}bd_1$ too large for the web. On the whole the formula gives results very nearly correct, but slightly in excess.

If we ignore the web altogether, but use D instead of $D_1$ for the lever arm of A, we have $m=AD$. (80)

Equation (79) is the proper practical formula for solid beams in all cases, though (76) may be used when greater accuracy is desired, which can scarcely be the case, however. It is a significant fact that equation (80) which ignores the web, and requires but one multiplication, produces results *more* accurate than the *most* accurate formulas in general use. We will now set forth the usual formulas and then exhibit the merits and demerits of them all, in a general comparison.

If in (76) we substitute for both D and $D_1$, the distance $g$ between the centers of gravity of the flanges, we get,

$$m=g(a+\tfrac{1}{6}B) \quad (81)$$

This is used by J. A. L. Waddell and others.

Writing $g$ for $D_1$ in 79 we get

$$m=g(A+\tfrac{1}{6}b) \quad (82)$$

Writing $g$ for the lever arm of the flange in (79) we find,

$$m=Ag+\tfrac{1}{6}bD_1 \quad (83)$$

This is the same as equation (5), Article 65, of Prof. Burr's "Elasticity and Resistance of the materials of Engineering." It is intended for use, and is extensively used. It is highly recommended by A. P. Boller, in his Highway Bridges, page 111.

If we consider the flanges for their whole depth, and the web as extending to the *middle* of the flanges and represent it by $b'$, we may write,

$$m=g(A+\tfrac{1}{6}b'). \quad (84)$$

Omitting allowances for extra diagonal resistances, recognised by Mr. Daniel K. Clark and others, the above is Mr. Clark's formula for eye beams, etc.

To show how erroneous the common formulas are, we will give the true resistances of the 13 eye beams rolled by Carnegie, also the resistances by our equations (76), (79), (80). By the side of these, we will give the resistances by equations (81) and (82) and add an example to illustrate equations (83) and (84).

Omitting No 13, which is not a practical beam, we observe that our equation (76) gives results almost exact; and that (79) is also practically accurate; while equations (81) and (82) give results in excess of about 5% and 10% respectively, and are therefore too erroneous to be countenanced in good practice. Besides, they involve far more labor than the far more accurate formulas recommended above. Thus are they doubly condemned

MOMENT OF RESISTANCE.

| Number of Beam. | True Moment. | Moment by (76). | Moment by (79). | Moment by (80). | Moment by (81). | Moment by (82). |
|---|---|---|---|---|---|---|
| 1 | 70.60 | 70 50 | 72 05 | 66.00 | 72.96 | 76.81 |
| 2 | 90.38 | 90.23 | 92.70 | 85.80 | 93.66 | 100.09 |
| 3 | 45 96 | 45 95 | 47.09 | 44.50 | 47.68 | 50.62 |
| 4 | 31.39 | 31.41 | 32 11 | 29.79 | 32.55 | 34.28 |
| 5 | 29.97 | 29.96 | 30.51 | 31.05 | 31.65 | 33.07 |
| 6 | 21.68 | 21.68 | 22.41 | 22 59 | 22.90 | 23.84 |
| 7 | 35 34 | 35.23 | 35.40 | 36.13 | 37.08 | 40.41 |
| 8 | 17.50 | 17 47 | 17 81 | 18.10 | 18.46 | 19.37 |
| 9 | 13.13 | 13.08 | 13.35 | 13.35 | 14 00 | 14 52 |
| 10 | 8.16 | 8 16 | 8.31 | 8.50 | 8 62 | 9.02 |
| 11 | 4.94 | 4.93 | 5.03 | 5.12 | 5 21 | 5.47 |
| 12 | 3.09 | 3.08 | 3.15 | 3.25 | 3 27 | 3.46 |
| 13 | 2.06 | 2.03 | 2.07 | 2.50 | 2.27 | 2.39 |

and the use of them therefore doubly absurd.

The following from Boller's Highway Bridges, page 111, will illustrate equations (83) and (84).

$$t=\tfrac{1}{2},D_1=13,h=1,b=5,D=15$$

$$\therefore A=5,b=6.5 \text{ and } g=14$$

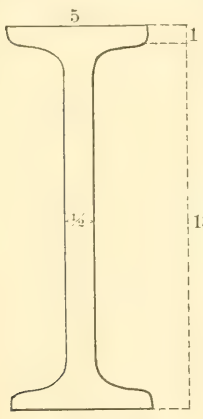



Fig. 36

Hence by (83)

$$m=14\times5+\frac{13\times6.5}{6}=70+14.083$$

$$=84.083$$

Now the true value of M is

$$\frac{5\times15^3-4.5\times13^3}{6\times15}=77.65$$

Hence the error $=6.43$

Now $6.43\div77.65=8.3\%$ nearly

By equation (84), we have

$$A=5,b'=14\times\tfrac{1}{2}=7 \text{ and } g=14.$$

Hence, $m=14(5+\frac{7}{8})=86.33$

Therefore this is $86.33-77\ 65=8.68$ in error.

This is an error of $8.68\div77.65=11.2\%$ nearly.

The formula deduced by Mr. Clark is, $m=g(A+.28888b')$ or $m=14(5+2.0216)$

$$=98.30$$

The error in the former result shows, however, the total error of the result due to mathematical errors in the corresponding formula.

We observe that equation (80) does indeed give results more accurate than any of the common formulas in use. This shows that a direct though random shot may rest nearer the center than others obliquely though deliberately aimed. Since the errors of these common formulas far exceed the allowable limit, it follows that the errors involved in their use are not fully appreciated by those who use them.

For example, the author of a desirable treatise on "Designing of Ordinary Iron Highway Bridges" uses Eq. (83) and considers it safe; though, comparing it with equation (76), we see that the excess given by it for the flanges exceeds many times the deficiency given for the web.

The author from whom Eq. (83) and the example under it are quoted, remarks that; "the above process for obtaining the value of R [that is, the moment of resistance, which we have represented by $m$] varies so fractionally from absolute truth, that the refinement of calculation, necessary to obtain mathematical exactness, is entirely unnecessary."

Eq. (83) gives, however, only a rough approximation to the truth, while Eq. (76) shows that a *proper* equation with no "refinement of calculation" whatever, is all that is necessary to obtain a practically perfect result. Indeed (76) is of the same form as (83), though (76) does not, for reasons already given, involve $g$. It is believed that all the practical formulas, so called, heretofore used contain the standard errors on this subject.

So far, we have said nothing about the metal in the curved corners, which it is customary and proper to take no account of. We will, however, show how the moment of resistance of the corners may be easily obtained.

In Fig. (35), draw the radii $u$P and $v$P and join P$m$. Let the angle $m$P$v=\theta$.

The area of $vmu\mathrm{P}=um\times u\mathrm{P}=(u\mathrm{P})^2 \tan\theta=r^2\tan\theta$.

The area of the sector $vu\mathrm{P}=\frac{1}{2}$ arc $vu \times u\mathrm{P}=(u\mathrm{P})^2\theta=r^2\theta$.

Therefore the area of the curved corner $=r^2(\tan\theta-\theta)$, and the area of the four corners $=4r^2(\tan\theta-\theta$.

Also $mx=\frac{1}{2}\mathrm{D}-\mathrm{H}$, and the strain at $m$ is equal to $\frac{\frac{1}{2}\mathrm{D}-\mathrm{H}}{\frac{1}{2}\mathrm{D}}=\frac{\mathrm{D}-2\mathrm{H}}{\mathrm{D}}$.

Hence the moment of resistance of the four curved areas is, very nearly,

$$4r^2(\tan\theta-\theta)\frac{\mathrm{D}-2\mathrm{H}}{\mathrm{D}}(\tfrac{1}{2}\mathrm{D}-\mathrm{H})$$

$$=2r^2(\tan\theta-\theta)\frac{(\mathrm{D}-2\mathrm{H})^2}{\mathrm{D}}$$

This averages about 2% in Carnegie's beams Nos. 1 and 2 and less than 1% in the others.

The moment of resistance of eye beams about any axis is best found by finding the moment of resistance of the flanges and the web (or parts of the flanges or web, if the axis passes through flange or web) separately, and adding; or, if the moment $m$ about $mn$ is known we may use the formula of reduction (64).

### Channel Bars.

The preceding formulas apply directly to channel bars, $a$ or A being the area of a flange, or total area of flanges on one side of the axis, when two (or more) channels are used; B or $b$ the area of a web or of the webs.

Since, however, the flanges of channels are thin, compared with the depths of the channels, those formulas give results for channels even more accurately than for beams.

### Center of Gravity.

Since the neutral axis is assumed to pass through the center of gravity of the section, it becomes necessary to find, in some cases, the position of the center of gravity, or at least of the axis passing through it, in order to find the moments of resistance and of inertia.

The center of gravity of a body may be defined as the center of the forces of gravity, assumed to be parallel, acting upon the body.

If the center of gravity of a body is supported, the body will be supported, for the forces of gravity balance about the center of gravity.

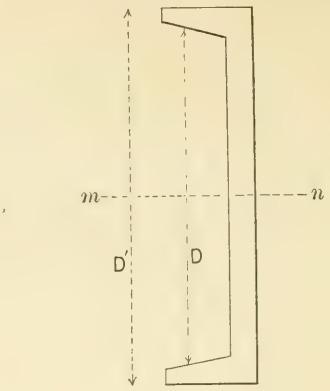


Fig. 37

For our purpose, it will be necessary to consider, to a limited extent only, the center of gravity of areas. The center of gravity of any regular polygon is at the center of the inscribed or circumscribed circle of a parallelogram at the intersection of the diagonals; of a plane triangle on the line joining the vertex with the middle of the base and at one-third the length of this line from the base; of a circle or ellipse, at the geometrical center of the figure, etc.

We observe that the center of gravity of any section symmetrical with reference to an axis, will be found on that axis; so that for such sections it is only necessary to find one line upon which the center of gravity is situated, the center of gravity being at the intersection of this line with the *symmetrical* axis.

To find the center of gravity of a double "T" eye beam with unequal flanges.

Let $a'$ be the area of the upper flange, $a''$ that of the lower flange and $b$ that of the web, as shown in Fig. 38, $d'$, $d''$ and $d$, the distances of their centers of gravity from the *base* of the beam, and $x$ the same for the whole figure.

Let A = the total area. Then taking moments about the base we have:

$$(a'+a''+b)x=bd+a'd'+a''d''$$

$$\text{or } x=\frac{bd+a'd'+a''d''}{a'+a''+b} \quad (85)$$

The center of gravity is, of course, on the center line of the web.

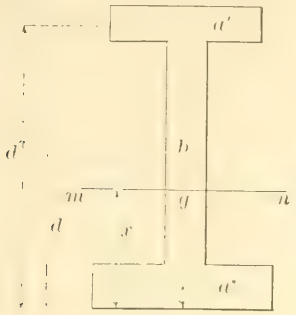



Fig. 38

Or, let the lever arms be measured from the center of gravity of the lower flange as indicated in Fig. 39.

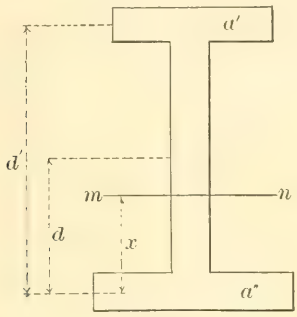



Fig. 39

In this case $d''=0$, and we have:

$$x=\frac{bd+a'd'}{a'+a''+b} \qquad (86)$$

If $h$=the thickness of the lower flange, the distance from the base of the beam to its center of gravity is,

$$x=\tfrac{1}{2}h+\frac{bd+a'd'}{a'+a''+b} \qquad (87)$$

These equations apply equally to the case in which the web is neglected, by putting $b=0$ in them.

Considering the web extending the whole depth of the beam, as in Fig. 40, we may easily find the distance of the center of gravity from the center of the beam.

The areas being represented as before, let $g$ be the center of gravity of the web, and $g'$ that of the beam. Let $gg'=x$ and let $d'$ and $d''$ be the distances from the centers of the flanges to the center of the web.

Taking moments about $g$, we have:

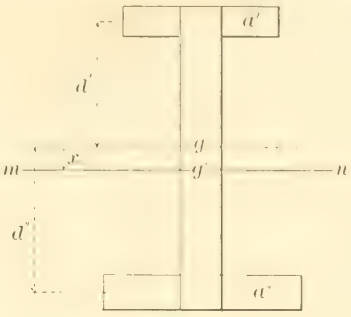



Fig. 40

$$(a'+a''+b)x=a''d''-a'd'$$

$$\text{or } x=\frac{a''d''-a'd'}{a'+a''+b} \qquad (88)$$

The above formulas apply without change to Deck Beams.

Let Fig. 41 represent a single "T."

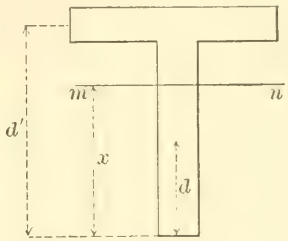



Fig. 41

Take moments about the end of the stem and find the distance from the end of the stem to the center of gravity of the section, $x=\dfrac{bd+a'd'}{a'+b}$. (89)

If $d$ and $d'$ are measured from the outside of the flange, eq. (89) will also give $x$, *measured from the same line.*

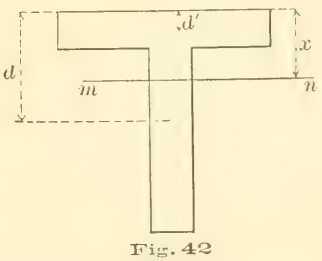



Fig. 42

Supposing the coefficients of elasticity for tension and compression to be equal, in which case the neutral axis does pass through the center of gravity of the sec-

tion, it is evident that the greatest strain would be on the end of the stem, and that the value of $x$, found from Fig. 41, would be the proper value to be used.

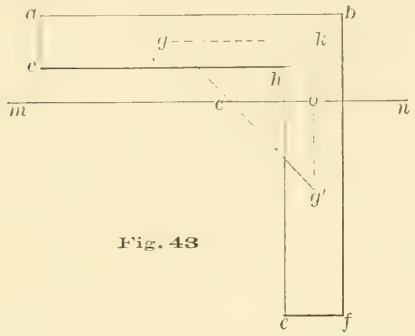



Fig. 43

It is evident that (89) applies without change to finding the position of the axis $mn$, through the center of gravity of angle irons, parallel to a leg, whether for equal or unequal legs. The position of this axis is all that is required in practice.

If, for any reason, the *center* of gravity is required, it may be easily found as follows:

Find $mn$ as above; then observing that the centers of gravity, $g$ and $g'$, of the legs are at their geometrical centers, join $g$ and $g'$. The intersection $c$ with $mn$ determines $c$, the center of gravity.

Or, let $a$= area of upper leg, and $a'$ that of the lower. Take $c$ such that

$$\frac{cg}{cg'}=\frac{a'}{a} \text{ or } \frac{cg}{gg'}=\frac{a'}{a+a'} \text{ or } cg=\frac{a'}{a+a'}\times gg' \qquad (90)$$

This determines the position of $c$. Drawing $gk$ and $g'k$ parallel to $ab$ and $bf$ we have:

$$\frac{Ok}{kg'}=\frac{cg}{gg'}=\frac{a'}{a+a'} \text{ or } Ok=\frac{a'}{a+a'}kg' \qquad (91)$$

This determines the position of the axis $mn$, with reference to $k$ and $g'$ and therefore with reference to $ab$ and $ef$.

For an obtuse angle iron, it is evident that the line $gg'$ will be divided at $c$ and therefore the line $kg'$ at $o$ in the same ratio as though the angle was right: and since the line $kg'$ is of the same length as for a right angled "angle," $ko$ is also the same. This gives an easy way of finding the position of $mn$.

The perpendicular distance of $mn$ from $ab$ and $ef$, are equal respectively to $or$ sin. $gkp$ and $op$ sin $gkp$.

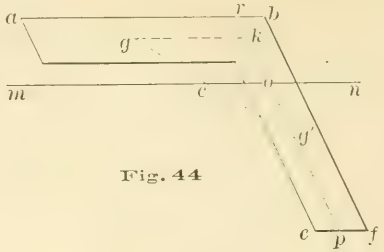



Fig. 44

To find the axis through the center of gravity of a channel parrallel to the web, consider each flange divided into a rectangle and a triangle as shown:

Let $t$=thickness of the web,
$h$=height of a flange,
$x$=distance from back of channels to the center of gravity of the channel,
$b$=area of the web,
$a$=area of the rectangular portion of a flange,
$a'$=area of the triangular portion of a flange,

and A=the total area of the channel.

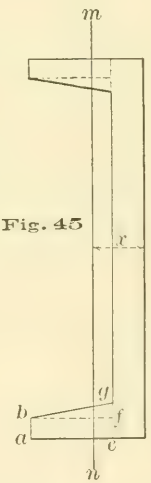



Fig. 45

Taking moments about the back of the channel we have,

$$(2a+2a'+b)x=b\times\tfrac{1}{2}t+2a(t+\tfrac{1}{2}h)+2a'(t+\tfrac{1}{3}h),$$

$$\text{or } x=\frac{t(2a+2a'+\frac{1}{2}b)+h(a+\frac{2}{3}a')}{2a+2a'+b} \qquad (92)$$

In a similar manner we easily find the center of gravity of all practicable forms.

### Deck Beams.

To find the moment of resistance about any axis.

If the beam is of the form shown in Fig. 46 which is the common one, eq. (65), will give the moment of the two

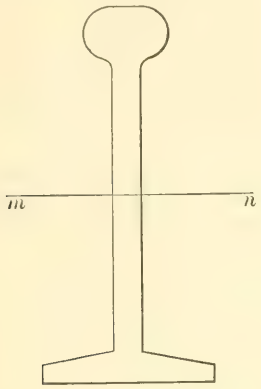



Fig. 46

semicircles or circle; the formula for number 2 of Table I. the same of each part of the web above and below the axis; and eq. (55) of the flange.

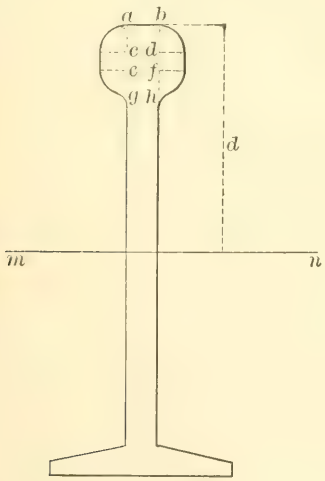



Fig. 47

If the beam is of the form shown in Fig. 47 eq. (68) or (69) will apply to the upper semicircle and eq. (70) or (71) to the lower, etc. It is easy to see, however, that the lever arm of the head as a whole, is in value between that of a circle whose diameter is $ag=h$ (say), and that of a rectangle of the same height. Either one of these lever arms may be used in this case with very great accuracy indeed.

### Star Iron.

To find the moment of resistance about the axis AB. Prolong the edges *ec*, *fd*, etc., to the axis as shown, Fig. 48.

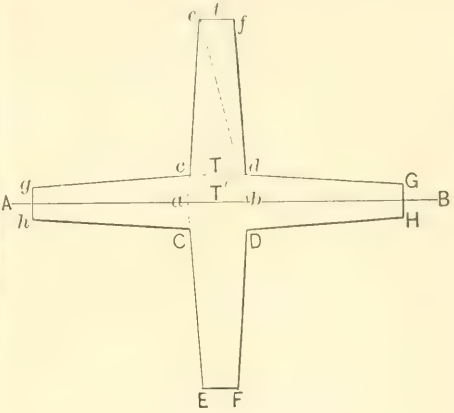



Fig. 48

Let $ef=t$, $cd=\mathrm{T}$ and $ab=\mathrm{T}'$, $e\mathrm{E}=\mathrm{D}$.

For the moment of resistance of the vertical stems, consider each divided into triangles by diagonals *be*, etc. Then from the formulas for numbers 3 and 4 of Table I.

$$\mathrm{M}_1=2\left\{\tfrac{1}{12}\mathrm{T}'\left(\frac{\mathrm{D}}{2}\right)+\tfrac{1}{4}t'\left(\frac{\mathrm{D}}{2}\right)^2\right\}=\tfrac{1}{24}\mathrm{D}^2(3t+\mathrm{T}') \tag{93}$$

Since the moment of the horizontal stem is very small compared with the vertical stem, we may consider the former to be flat, as was done in treating the flanges of the eye beams in Fig. 35. We thus find the moment of resistance of the horizontal stem to be

$$\mathrm{M}_2=\tfrac{1}{48}\,\frac{\mathrm{D}-\mathrm{T}}{\mathrm{D}}(t+\mathrm{T})^3 \tag{94}$$

(93) and (94) give for the total moment

$$\mathrm{M}=\tfrac{1}{24}\mathrm{D}^2(3t+\mathrm{T}')+\tfrac{1}{48}\,\frac{\mathrm{D}-\mathrm{T}}{\mathrm{D}}(t+\mathrm{T})^3 \tag{95}$$

or $\mathrm{M}=\tfrac{1}{24}\mathrm{D}^2(3t+\mathrm{T}')+\tfrac{1}{48}(t+\mathrm{T})^3$, nearly. (96)

These represent to the best advantage the usual formulas for this case. We

will, however, derive a formula twice as short and three times as accurate.

We notice that the area cut off, in rounding the four corners at $e$, $f$, E and F is a little less than the difference between the areas of a square and a circle, whose diameters are each equal to $t$.

This difference is $=t^2-\frac{\pi}{4}t^2=.2146t^2$.

The lever arm of this area is a little less than $\frac{D}{2}$. Hence the moment is a little little less than

$$.2146t^2\frac{D}{2}=.1073t^2D \text{ or } M'=\tfrac{1}{10}t^2D,$$

very nearly. (97)

The total moment is, therefore,

$$M=\tfrac{1}{24}D^2(3t+T')-\tfrac{1}{10}Dt^2+\tfrac{1}{48}\frac{D-T}{D}(t+T)^3 \quad (98)$$

In regard to eq. (98), we observe that the term $\frac{1}{10}Dt^2$ is usually and properly disregarded; and that the term $\frac{1}{48}\frac{D-T}{D}(t+T)^3$, as well as the quantity $\frac{1}{24}D^2(T'-T)$ is in practical cases much smaller, and both together smaller than $\frac{1}{10}Dt^2$. Hence

$$\tfrac{1}{10}Dt^2-\tfrac{1}{24}D^2(T'-T)-\tfrac{1}{48}\frac{D-T}{D}(t+T)^3 = 0, \text{ very nearly.}$$

Adding this to (98), we obtain the moment of resistance

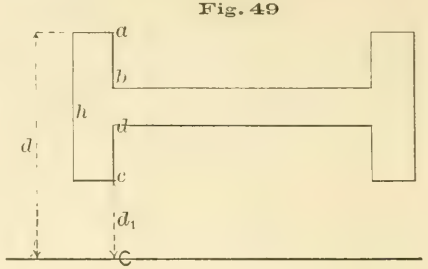
$$=M=\tfrac{1}{24}D^2(3t+T) \quad (99)$$

This is believed to be the simplest and most accurate approximate formula possible to deduce. The following table will show that, taking all the forms in Carnegie's book as a test, eq. (99) is three times as accurate as (96), or as the ostensibly accurate results (and they are sufficiently accurate) given in Carnegie's "Pocket Companion:"

| Size. | Thickness in inches at the end and root of flange. | Eq. (96) or Carnegie's. | True moment eq. (98). | Eq. (99). |
|---|---|---|---|---|
| 4 ×4 | $\frac{9}{16}$ | 1.16 | 1.11 | 1.13 |
| $3\frac{1}{2}\times 3\frac{1}{2}$ | $\frac{1}{2}$ | 0.85 | 0.80 | 0.83 |
| 3 ×3 | $\frac{5}{16}$ $\frac{1}{2}$ | 0.55 | 0 52 | 0.53 |
| $2\frac{1}{2}\times 2\frac{1}{2}$ | $\frac{5}{16}$ $\frac{13}{32}$ | 0 36 | 0.34 | 0.35 |
| 2 ×2 | $\frac{1}{4}$ $\frac{11}{32}$ | 0.20 | 0.19 | 0.19 |
| $1\frac{1}{2}\times 1\frac{1}{2}$ | $\frac{3}{16}$ $\frac{5}{16}$ | 0.087 | 0.082 | 0.082 |

To find the moment of resistance of an eye beam, the neutral axis being any line parallel to the center line of the web.

Fig. 49




Let $ac=h$, $bd=t$, $Cd=d_2$.

The lever arm of the flanges is by eq. (55)

$$l=d_1+\tfrac{1}{3}\frac{h^2}{d}=d_1+.33\frac{h^2}{d} \quad (55)$$

To find the lever arm of the web. Supposing the strain at $b$ equal to unity, the same equation would give the lever arm $=d_2+\frac{1}{3}\frac{t^2}{(d_2+t)}$. But the strain at $b$ is $\frac{bC}{aC}=\frac{d}{d_2+t}$, and hence the lever arm $=l'$

$$=\left(d_2+\frac{t^2}{3(d_2+t)}\right)\frac{t^2}{d_2+t}=\frac{d_2^2+d_2t}{d}+\frac{t^2}{3d}=$$

$$\frac{(d_2+\frac{1}{2}t)^2}{d}+\frac{t^2}{12d}=\frac{(d-\frac{1}{2}h)^2}{d}+\frac{t^2}{12d}=d-h$$

$$+\frac{h^2}{4d}+\frac{t^2}{12d}=d_1+\frac{h^2}{4d}+\frac{12d}{t^2}=d_1+\frac{h^2}{4d},$$

very nearly, (55′)

We observe that $\frac{t^2}{12d}$ will not amount, in average cases, to nearly one hundredth part of $\frac{h^2}{4d}$, or to scarcely a perceptible part of the lever arm.

When $t=h$ (55′) gives $l'=d+\frac{h^2}{4d}+\frac{h^2}{12d}$ $=d_1+\frac{h^2}{3d}=l$ as it ought. An arithmetical mean of the above lever arms used for both stem and flanges will give results sufficiently accurate in almost all cases.

This lever arm is, $l=d+\frac{1}{2}\left(\frac{h^2}{3d}+\frac{h^2}{4d}\right)=d_1$

$$+\frac{7h^2}{24d}=d_1+.29\frac{h^2}{d}(55'')=d_1+.3\frac{h^2}{d}$$

nearly, (55‴)

If $a$=area of each flange and $b$ that

of the web, we have from (55) and (55′), for the beam,

$$M_1 = 2a\left(d_1 + \frac{h^2}{3d}\right) + b\left(d_1 + \frac{h^2}{4a} + \frac{t^2}{12d}\right)$$

$$= 2a\left(d_1 + \frac{h^2}{3d}\right) + b\left(d_1 + \frac{h^2}{4a}\right) \text{ very nearly (100)}$$

or from (55‴), $M_1 = (2a+b)\left(d_1 + .3\frac{h^2}{d}\right)$ (101)

### Channel Bars.

Let $ac=h$, $bc=t$ and $an$ ($n$ is at the middle of $bc$)$=h_1$, etc. The lever arm of the flanges, as we have just seen is $l=d_1 + \frac{h^2}{3d}$. Observing that, in reference to the web, $\frac{1}{2}h$ in Fig. 49, is the same as $h_1$

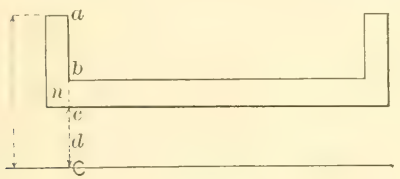



Fig. 50

in Fig. 50, eq. (55) gives for the lever arm of the web

$$l' = \frac{(d-h)^2}{d} + \frac{t^2}{12d} = \frac{(d-h)^2}{d} \text{ very nearly (102)}$$

The notation being as before, the moment is therefore

$$= M_1 = 2a\left(d_1 + \frac{h^2}{3d}\right) + b\frac{(d-h)^2}{d} \quad (103)$$

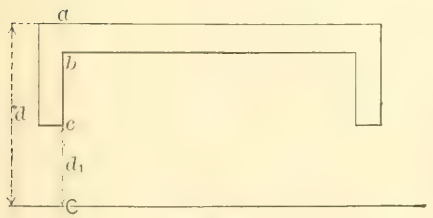



Fig. 51

In Fig. 51 let $ac=h$, $bc=t$, etc. Eq. (55) gives the lever arm of the flanges,

$$= l = d + \frac{h^2}{3d};$$

and the lever arm of the web

$$= l'' = d - t + \frac{t^2}{3d} = d - t, \text{ very nearly.}$$

Hence $M_1 = 2a\left(d_1 + \frac{h^2}{3d}\right) + b\left(d - t + \frac{t^2}{3d}\right)$

$$= 2a\left(d_1 + \frac{h^2}{3d}\right) + b\,(d-t) \text{ very nearly (104)}$$

These formulas evidently apply without change to angle irons, as shown in Fig. 52.

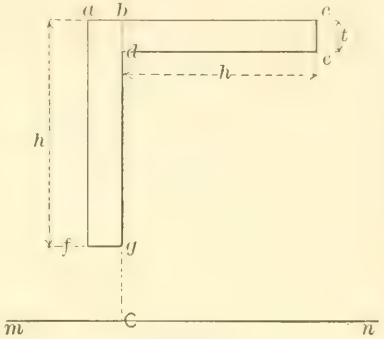



Fig. 52

We shall now apply the preceding formulas to finding the moment of resistance of compound beams, girders, etc., selecting our examples for the purpose from actual practice. We shall deduce formulas exceedingly short and practically perfectly accurate. We will first consider angle irons.

Referring to Fig. 52 the lever arm of the vertical leg is equal to $d - h + \frac{h^2}{3d}$, and of the horizontal leg to $d - t + \frac{t^2}{3d} = d - t$ very nearly.

Hence, supposing $bc=af=h$, we have the lever arm of the angle equal to an arithmetical mean between the lever arms of the legs$=l=\frac{1}{2}\left(d - t + d - h + \frac{h^2+t^2}{3d}\right)$

$$= d - \tfrac{1}{2}(h+t) + \frac{h^2+t^2}{6d} (105); \; = d - \tfrac{1}{2}(h+t)$$

nearly, which shows that the extremity of the lever arm, or the center of moments, is in this case nearly at (though a little above) the middle of $dg$.

Suppose, now, the horizontal leg to be shortened an amount $hc=ab=t$, so that $ah=af=h$, the legs being equal; to find the decrease in the lever arm of the angle. M, the middle point of $dg$, is the center of moments, very nearly, for the

angle $acf$; and $o$ the same for the angle $ahf$. Let $mo=x$.

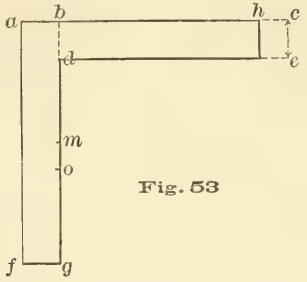



Fig. 53

Taking moments about $m$, and observing that the areas of the parts of the angle are as their lengths, we have:

$mo(af+bh)=do\times hc$, or $x(2h-t)=\frac{1}{2}(h-t)t$

$$\therefore\ x=\frac{t(h-t)}{4h-2t}<\frac{t(h-t)}{4h-4t}=\tfrac{1}{4}t,\quad \text{or}\quad x=\tfrac{1}{4}t$$

nearly. Subtracting this from (105), we have for equal legs—

$$\text{Lever arm}=l'=d-\tfrac{1}{2}(h+t)-\left(\frac{t}{4}-\frac{h^2+t^2}{6d}\right) \quad (105')$$

or effective depth

$$=\mathrm{D}'=\mathrm{D}-(h+t)-\left(\frac{t}{2}-\frac{h^2+t^2}{3d}\right) \quad (106)$$

Now, suppose the vertical leg$=h$ and the horizontal leg$=h+e$, then as above we readily find,

$$x=\frac{e(h-t)}{4h+2e}<\frac{eh}{4h+2e}<\frac{eh}{4h}=\tfrac{1}{4}e.$$

Applying this to all the forms rolled by Carnegie, taking average thickness of legs, we find the average to be

$$x=.172e=\tfrac{1}{6}e \text{ very nearly.}$$

Hence for unequal legs the lever arm is,

$$l''=d-\tfrac{1}{2}(h+t)-\left(\frac{t}{4}-\frac{h^2+t^2}{6d}\right)+\tfrac{1}{6}e \quad (105'')$$

And the effective depth is

$$\mathrm{D}''=\mathrm{D}-(h+t)-\left(\frac{t}{2}-\frac{h^2+t^2}{3d}\right)+\tfrac{1}{3}e \quad (107)$$

$\frac{t^2}{3d}$ is too small to take note of.

Again, $\frac{h^2+t^2}{l}$, is only a small part of unity, and furthermore, in no properly proportioned beam can this expression differ from $\frac{t}{2}$ by an appreciable amount—by an amount scarcely affecting the decimal places of the result. This becomes apparent when we reflect that, approximately, $t\propto h\propto \mathrm{D}$, and hence

$$\frac{h^2+t^2}{3d}\text{ or }\frac{h^2}{3d}\propto\frac{d^2}{d}\propto d\propto \mathrm{D},\text{ and }\frac{t}{2}\propto\frac{h^2+t^2}{3d}.$$

For an average case, let $t=\frac{3}{8}$, $h=3$, $\mathrm{D}=30$, we have

$$\frac{t}{2}-\frac{h^2}{3d}=\tfrac{3}{16}-\tfrac{1}{5}=\tfrac{1}{80}=.012.$$

The equations become, therefore, for equal legs,

$$\mathrm{D}=\mathrm{D}-(h+t), \quad (108)$$

And for unequal legs,

$$\mathrm{D}''=\mathrm{D}-(h+t)+\tfrac{1}{3}e. \quad (109)$$

In case of unlike angles for the upper and lower flanges we have the effective depth

$$=\mathrm{D}''=\mathrm{D}-\tfrac{1}{2}(h+h'+t+t')+\tfrac{1}{6}(e+e') \quad (110)$$

in which the accented letters refer to the angles on one of the flanges.

If $t=t'$, effective depth

$$=\mathrm{D}''=\mathrm{D}-\tfrac{1}{2}(h+h'+2t)+\tfrac{1}{6}(e+e') \quad (111)$$

### Plate Girders.

Let Fig. 54 represent a single plate girder formed by a plate and four angles.

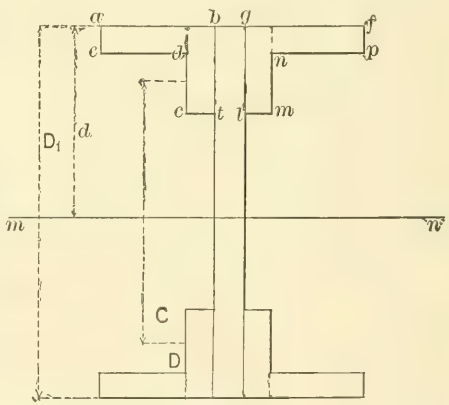



Fig. 54

In proportioning built beams, it is understood to be the duty of the web to maintain a rigid connection between the flanges; and it is usual to assume that "the flanges sustain all the horizontal strains and no other, and that the web sustains only the vertical strains."

Some engineers treat the web, as also resisting horizontal strains, the same as a beam with no flanges; and since it can

only partially do so, they attempt to correct the assumption by allowing a proportionately smaller strain per □″ of cross section. But this is plainly unphilosophical, since the ratio of the area of the web to that of the flanges is not constant. If anything at all is allowed for the web in resisting horizontal strains, such a part only of its resisting power as a beam, should be allowed as experiment will justify.

The flanges are frequently made equal, the supposition being, however, that the resisting power of the cross section of the compression flange in such cases, is somewhat greater than that of the net area (rivet holes deducted) of the tension flange.

I will in the following examples, give the results by my formulas, as well as those by the usual formulas, noting the errors of the latter.

*Example* 1. Web $20'' \times \frac{1}{4}''$; 4 angles $2\frac{1}{4}'' \times 2\frac{1}{4}'' \times \frac{1}{4}''$, as shown in Fig. 54. Instead of multiplying the area of each flange by its lever arm, we may multiply the area of one flange by twice its lever arm, or the "effective depth" of the beam.

Now, by (108), the effective depth $= D_1 = 2d - (h + t) = 20 - 2\frac{1}{2} = 17.5$. And the area of the two angles is equal to $a = 2\frac{1}{8}$.

Hence the moment by 77 is equal to $D_1 a = 17.5 \times 2.12 = 37.10$.

The true moment found by equation (106) is 37.28.

Taking the effective depth equal to the clear depth between the horizontal legs of the angles, which is the least value used in general practice, and, therefore, leads to the *least* error, we find the moment $= 19.5 \times 2\frac{1}{8} = 41.44$, showing an error of 4.08, or about 11%.

*Example* 2. Web $27'' \times \frac{1}{4}''$; 4 angles $3'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$.

The effective depth by (109)
$= D - (h + t) + \frac{1}{3}e = 27 - 2\frac{3}{4} + \frac{1}{6} = 24.42$.

The area of two angles $= 2.62$; and $24.42 \times 2.62 = 63.98$.

The true moment is 64.14.

*Example* 3. The floor beams of a bridge are $17\frac{2}{3}$ feet apart and $17\frac{1}{6}$ feet long from center to center of pins; and fully stiffened so that their length need not be regarded when considering the strains upon them. Roadway, 16 feet wide in the clear. Rolling load, 80lb per □ foot, or 1280lb per lineal foot of bridge.

A beam, web $20'' \times \frac{1}{4}''$ and 4, $3'' \times 2''$, 4lb angles ($\frac{1}{4}$ inch thick, area 1.19 □″) is proposed. Iron supposed to resist 8,000 pounds per square inch in compression and 10,000 in tension. Is the beam sufficiently strong?

1° The dead load per lineal foot of bridge is:

| | Pounds. |
|---|---|
| Flooring (oak), $2\frac{1}{2} \times 16 = 40$ ft.; $40 \times 4\frac{1}{2} = 180$ | |
| 11 joists (pine), $\frac{3 \times 12 \times 11}{12} = 33$ ft.; $33 \times 3\frac{1}{3} = 110$ | |
| 2 felloe guards, $\frac{4 \times 6 \times 2}{12} = 4$ ft.; $4 \times 3\frac{1}{3} =$ | 13 |
| Total, | 303 |

Rolling load, $16 \times 80 = 1280$ pounds.
Total per lineal foot, 1583 "

$1583 \times 17\frac{2}{9} = 27263$ = the external load on the beam.

Area of web $= 20 \times \frac{1}{4} = 5$ □″
and weight $= \frac{5 \times 10}{3} = 16.67$

| | |
|---|---|
| Weight of angles per foot $= 4 \times 4 =$ | 16.00 |
| Total, | 32.67 |
| Add for stiffening angles, filling plates and rivets, 20% = | 6.53 |
| | 39.20 |

Hence weight of beam $= 39.2 \times 17\frac{1}{6} = 673$
Add, 27263
Total load $= 27936$

The moment of the load
$= m = \frac{27936 \times 17\frac{1}{6} \times 12}{8} = 719352.$

The compressive side of the beam is the weaker.

The effective depth of angles is by (109), $D_1 = 20 - 2\frac{1}{4} + \frac{1}{3} = 18\frac{1}{12}$, hence, *considering the web fully effective*, equation (76) gives for the moment of resistance of the beam;

$m' = 8000(18\frac{1}{12} \times 2.38 + \frac{1}{6} \times 5 \times 20) = 477630$

Now $\frac{4}{7}\frac{7}{1}\frac{7}{9}\frac{6}{3}\frac{3}{5}\frac{0}{2} = 66$ nearly; and we find that the beam has at most, *according to the specifications*, about two-thirds of the required strength or capacity.

2° Disregarding the coefficient 8,000, and considering the tensile side to be the weaker. Using $\frac{5}{8}''$ rivets in $\frac{11}{16}''$ holes, the angles being $\frac{1}{4}''$ thick, the area lost

by a rivet in each angle is $2\times\frac{1}{16}\times\frac{1}{4}$ $=.344''$.

Hence the effective area of a flange is $2.375-.344=2.03''$, and we have moment of resistance of beam

$=10000(2.03\times18\frac{1}{12}+\frac{5}{6}\times20)=533792.$

The beam has, under *this* supposition, a capacity of $\frac{5}{7}\frac{3}{1}\frac{3}{9}\frac{7}{3}\frac{9}{5}\frac{2}{2}=74\%$ of that required.

3° Computing, according to the Carnegie formula, coefficients and all, which formula was professedly (though in view of the 8000 coefficient, inconsistently) used in this case; we have the moment of resistance of beam equal to

$$10000\times2.38\times20=476000.$$

Now, $\frac{4}{7}\frac{7}{1}\frac{6}{9}\frac{0}{3}\frac{0}{5}\frac{0}{2}=.66$, showing that the beam has over 66%, or about $\frac{2}{3}$ of required capacity.

4° Referring to the Carnegie table we find the area required for each flange $=3.58$ square inches, and as we have an area equal to 2.38 square inches, the capacity of beam is $\frac{2.38}{3.58}=.66$, or 66% as above. We will try a web plate $\frac{1}{4}''\times24''$.

Flanges, four, $3''\times2''\times\frac{5}{16}''$ (5lb angles).

| | | |
|---|---|---|
| Weight of web $=\frac{\frac{1}{4}\times24\times10}{3}$ | | 20 |
| Weight of angles | $=4\times5=$ | 20 |
| | | 40 |
| Add 20% | | 8 |
| | | 48 |

Hence weight of beam $=48\times17\frac{1}{6}=824$

Add 27263

Total load 28087

The moment of the load

$$=m=\frac{28087\times17\frac{1}{6}\times12}{8}=723240.$$

The effective depth of flanges

$=24-(2+\frac{5}{16})+\frac{1}{3}=22.02.$

Hence $m'=8000(aD_1+\frac{1}{6}BD)$

$=8000(2.98\times22.02+24=717040.$

The beam is therefore about one-half of one per cent. only short of the capacity required, and is therefore satisfactory.

According to Carnegie we have moment of resistance $=10000\times2.98\times24$ $=715200$, showing a deficiency of about 1%.

A plate girder with flange plates. The effective depth of the flange plates is but little greater than the web plate D.

To find the effective depth of the angles we observe that were the strain at $c$ unity, the effective depth by (109) would be $D-(h+t)+\frac{1}{3}e$. But the strain at $c$ is equal to

$$\frac{mc}{ma}=\frac{d}{d+t_1}=\frac{D}{D+2t_1}=\frac{D-2t_1}{D}\text{ nearly.}$$

$$=1-\frac{2t_1}{D}\text{ nearly.}$$

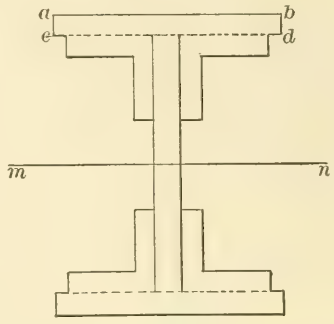



Fig. 55

Hence the effective depth is equal to

$$D''=[D-(h+t)+\tfrac{1}{3}e]\left(1-\frac{2t_1}{D}\right)=D-(h+t)$$
$$+\tfrac{1}{3}e-2t_1+$$
$$=D-(h+t+2t_1)+\tfrac{1}{3}e\text{ nearly.}\quad(109')$$

For equal legs, $e=o$, and we have effective depth

$=D'=D-(h+t)-2t_1=D-(h+t+2t_1)$ (108′)

Eqs. (108′) and (109′), compared with (108) and (109), show that the reduced effective depth of a section covered by a plate is approximately equal to the effective depth without the plate, less the thickness of the plate. Of course the principle applies to all sections situated substantially the same.

For unequal legs, with plates whose thickness is $t_1$, eqs. (110) and (111) become,

$$D''=D-\tfrac{1}{2}(h+h'+t+t')+\tfrac{1}{6}(e+e')-2t_1 \quad (110')$$

and $$D''=D-\tfrac{1}{2}(h+h'+2t)+\tfrac{1}{6}(e+e')-2t_1 \quad (111')$$

For one plate we write in those several equations, $t_1$, for $2t_1$. The effective depth is to be used with the weaker flange.

*Example*—A track stringer (17 feet and one inch long from center to center of floor beam).

Web, $21\frac{1}{2}''\times\frac{5}{16}''\times16'\ 11\frac{1}{2}''$ long.

Upper flange. 2 angles $3\frac{1}{2}''\times3''\times\frac{3}{8}''$, one plate, $8''\times\frac{3}{8}''$.

Lower flange, 2 angles, $5''\times4''\times\frac{3}{8}''$.

(111′) gives, effective depth
$=21.5-\frac{1}{2}(3+4+\frac{3}{4})+\frac{1}{6}\times\frac{3}{2}-\frac{3}{8}=17.5$.

The lower flange is the weaker.

Area of lower flange is 6.47 □″.

Hence the moment is $6.47\times17.5=113.22$.

Were the depth of the web taken for the effective depth, the error would be, $\frac{21.5-17.5}{17.5}=23\%$ nearly.

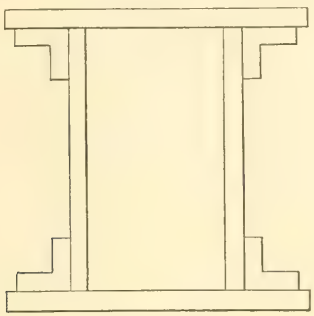


Fig. 56

A box girder (Fig. 56) may be treated precisely as a plate girder, the former having two web plates, the latter one.

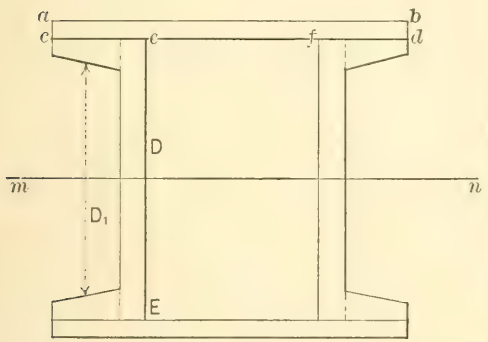



Fig. 57

A, box girder as shown in Fig. 57.
D being the depth of channels;
$D_1$ average depth between flanges;
$b$ the area of the webs;
$a$ the area of flanges on one side of the axis;
$t$ average thickness of flange;
A the area; and
$t_1$ the thickness of a plate.

Eq. (55) gives the effective depth of plates but little greater than D; and the same eq. observing the remark under eqs. (108′) and (109′) shows the effective depth of the web to be but little greater than $D-2t_1$ and that of the flanges a little greater than $D_1-2t_1=D-2t-2t_1$.

The effective depth for the channels and plates together will not vary much from $D-2t_1$.

Hence the moment

$$M=(a+A+\tfrac{1}{6}b)\ (D-2t_1) \quad (112)$$

*Example*—15″ channels.

Let plate be $12''\times\frac{1}{2}''$;

Area of two flanges=4.125.

Area of two webs=15.75 and $D-2t_1=14$.

Hence $m=14(6+4.125+2.62)$
$=14\times12.75=178.5$.

If the channels are turned inward the moment will, of course, be the same.

In a similar way may the effective depth and moment of resistance of any form of girders be found.

### Solid Eye Beams.

*Example*—Floor beams $17\frac{1}{2}$ feet apart and $17\frac{1}{6}$ feet from center to center of pins. Roadway 16 feet wide in the clear. Rolling load 1280 pounds per lineal foot of bridge. Allowable strain 10,000 pounds per square inch.

A 12″, 42 pound eye beam (Carnegie No. 3) is used. Is it sufficient for the load? The moment of the beam is $45.96\times10000=459600$.

Load per lineal foot of bridge;
Flooring (pine 3″)
$3\times16=48$ ft., $48\times3\frac{1}{2}=160$ pounds.
9 joists (pine $3''\times12''$)
$3\times9=27$ ft., $27\times3\frac{1}{3}=90$
2 wheel guards (pine $6''\times6''$)
$2\times3=6$ ft., $6\times3\frac{1}{3}=20$
270
Add 1280
1550

Load on the beam
$=1550\times17\frac{1}{2}=27125$ pounds.
Weight of beam $=17\frac{1}{6}\times42=721$
Total load on beam 27846

The moment of the load
$$=\frac{27846\times17\frac{1}{6}\times12}{8}=717034.$$

Now $\frac{459600}{717034}=.64$. This shows that

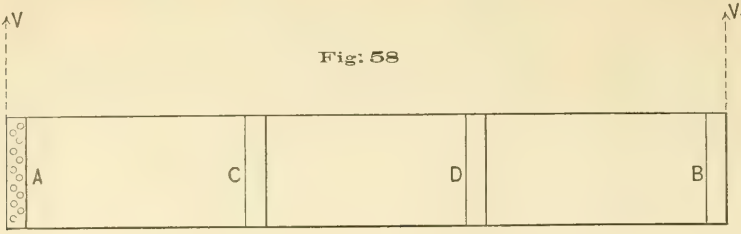



Fig. 58

the floor beam has but 64% of the required capacity. A 15″, 50lb beam has a moment of resistance = 70.6×10000 =7060 0, and has therefore a capacity of $\frac{7060000}{11170034}$=.98, or 98% of that required, and may be considered sufficient.

Complete design for a plate floor beam with cover plates for a single track railway bridge.

Let the beam be 15 feet between supports, total length 16 feet; and let AC= DB=5$\frac{1}{6}$ feet=62 inches and CD=4$\frac{2}{3}$ feet =56 inches. The ends of the track stringers rest at C and D.

Let the web plate be 28 inches deep and $\frac{3}{8}$ of an inch in thickness. The flanges alone are supposed to resist the longitudinal strains of compression and tension.

We will suppose the beams to be 16 feet apart, and the wheel spaces 7 feet; and that 24.000 pounds rest upon each pair of wheels. The train weight on a beam is therefore

$24,000+2\times\frac{9}{16}\times24,000+2\times\frac{2}{16}\times24,000$

=57,000 pounds, or 28,500 at C and at D.

We will assume the weight of beam to be 100 pounds per foot, or 1,600 pounds; and that of the track stringer 80 pounds per foot, or 1,280 pounds. Hence the external weight on the beam at C or at D is

28,500+640=29,140 pounds.

The reaction V at A, is equal to

29,140+800=30,000 pounds nearly.

The weight of the beam between A and C is $5\frac{1}{6}\times100=520$ pounds.

Hence the bending moment at C is

30,000×62—520×31=1,844,000 inch pounds nearly.

To proportion the flanges for the middle portion of the beam.

We will try $3''\frac{1}{2}\times3''\times\frac{1}{2}''$ angle irons (10.4 lb., 3.11 □″) with a plate $9''\times\frac{5}{16}''$.

We will use $\frac{3}{4}''$ rivets in both legs of the angles:

| | |
|---|---|
| Area of two angles is | 6.22 □″ |
| Area lost by a rivet, is $2\times\frac{3}{4}\times\frac{1}{2}$ | .75″ |
| Net area is | 5.47″ |
| Net area of plate is $(9—2\times\frac{3}{4})\times\frac{5}{16}$ | 2.34″ |
| Total area is | 7.81″ |

For an approximate result we may assume the effective depth of plate and angles together to be equal to the distance between the lines of centers of rivets in the vertical legs of the angles.

This is approximately equal to D—$h$. In this case D—$h$=28—3=25.

We will take the allowable tensile and compressive resistances in the flanges to be 10,000 pounds per square inch.

Hence, moment of resistance

=10,000×7.81×25=1,952,500.

This is about 110,000 or 6% in excess of requirements.

We will therefore try the above angle-irons, with a plate $8''\times\frac{5}{16}''$, computing more carefully

| | Square Inches. |
|---|---|
| Net area of angles | =5.47 |
| Net area of plate=$6\frac{1}{2}\times\frac{5}{16}$ | =2.03 |
| Total, | 7.50 |

The lever arm of angles =28—$(3+\frac{1}{2}+\frac{5}{8})+\frac{1}{6}$=24 04 inches, and that of the plate =28 "

Hence moment of resistance

=10,000 (5.47×24.04+2.03×28)
=10,000 (131.5+56.8)=1,315,000
+568,000=1,883,000 inch pounds.

This is about 2% in excess of requirements, and may be considered satisfactory.

To find the number of rivets required in the vertical legs of the angle irons.

The total strain in the flanges must pass through these rivets. Hence, assuming the rows of rivets to be 25 inches apart, as above, the flange strain at C is

$$1,844,000 \div 25 = 73,760 \text{ pounds,}$$

or 36,880 pounds on each angle.

The bearing value of a $\frac{3}{4}''$ rivet through a $\frac{3}{8}''$ plate is, by Table IV., 4,220 pounds. Hence number required is $\frac{7}{4}\frac{3}{2}\frac{6}{2}\frac{8}{0}\frac{0}{0} = 18$.

Since the rivets sustain double shear in the flanges, Table IV. shows that the resistance of the rivets to shearing is much greater than to bearing, and that the former need not therefore be considered.

Now, the lever arm of the strain on the flanges is $\frac{1}{2}(\frac{3}{8} + \frac{1}{2}) = \frac{7}{16}''$, and the moment, $36,880 \times \frac{7}{16} = 16,135$ inch pounds. The moment of a rivet is 780 inch pounds. Hence number of rivets required to resist bending is $\frac{1}{7}\frac{6}{8}\frac{1}{0}\frac{3}{0}\frac{5}{0} = 21$.

We will insert, say, 24 rivets in the 62 inches from A to C, spacing about $2\frac{1}{2}$ inches apart.

The Table shows that with a $\frac{3}{8}''$ plate the double shearing is equal to the bearing resistance for $\frac{1}{2}''$ rivets and over, and we have just found that the bending is nearly equal to the bearing resistance for $\frac{3}{4}''$ rivets and over.

Now, since the bearing resistance increases as the product of the diameter of rivet and thickness of plate, and the shearing resistance as the square of the diameter of the rivet, and the bending resistance as the quotient of the cube of the diameter of the rivet, divided by the thickness of the plate and the angle leg; and since the thickness of the plate and that of the angle legs increase approximately with the diameter of the rivets, it is evident that the three resistances increase or decrease approximately together.

With the plates and angles used, however, it will be found that in general, the smaller rivets are weaker for bending than bearing and the larger rivets stronger.

It is unnecessary to compute the strain at any point between C and D, for it would differ from the strain at C or D by an amount due to the weight of the beam only, which is very small.

To find the length of the cover plates.

Since the weight of the beam is small compared with the load, the flange stress or moment of flange stress increases almost uniformly from A to C.

Hence an increased section is first needed at $(5.47 \div 7.50) \times 62 = 45$ inches from A.

If, however, the end of the cover plate is placed at the above point, the angles will be strained to the allowable limit at that point, the stress will decrease quite rapidly on either side of it, and the beam will be somewhat distorted in consequence.

It is better, therefore, to extend the end of the plate from the point in question one-fourth or one-third of the distance to A.

We will use a cover plate 10 feet long, reaching from a point $2\frac{1}{2}$ feet from A to a point $2\frac{1}{2}$ feet from B.

We will use $\frac{3}{4}''$ rivets to bind the cover plate to the angles, and they should, so far as possible, be pitched half way between the rivets in the other leg of the angle irons.

It is customary to extend the cover plate, say, one and a half times its width, but the proper distance to extend the cover plate does not so much depend upon its width as upon the space between its end and the end of the beam, as above pointed out.

We have so far confined our attention to the tension flange, but the same design is surely sufficient for the compression flange, since the resistance of wrought-iron for compression is fully equal to that for tension, and the rivet holes in the compression flange need not be deducted.

The upper (compression) flange is frequently constructed with a cover plate, the lower flange with heavier angle irons, without a cover plate.

While less material is lost in the tension flange by rivet holes, without than with a cover plate, the use of a cover plate above and none below, leaves the flanges unsymmetrical. Besides, the effective depth is less without than with cover plates, and hence the advantage of the above arrangement is not so great as might be supposed. For example, the gross material in the above flange is $6.22 + 2.50 = 8.72$ square inches.

Gross material in two angle irons,
$4'' \times 3\frac{1}{4}'' \times .60''$, is..... 8.72 sq. ins.
Area lost by a rivet is $.2 \times .60 \times \frac{3}{4}$. .90 " "

Net area of angles..... $=7.82$ " "

Effective depth of angles

$$=28-(3\tfrac{1}{2}+.60)+.17=24.07.''$$

Now, $7.82 \times 24.07 \times 10{,}000 = 1{,}882{,}274$, which is just about the same as for the flange found above. It is generally best to use a cover plate on each flange or none at all.

To find the number of rivets in the cover plate.

The total stress carried by the cover plate is $2.03 \times 10{,}000 = 20{,}300$ pounds.

The bearing value of a rivet is 4,220 pounds. Hence, the number of rivets required between the end of the plate and the point C is

$$\frac{20300}{4220} = 5.$$

Fig. 59 shows the left half of the beam AEM, with the half cover plate EM, AE $=30$, EC $=32$, and CM $=28$ inches. Placing rivets 2 inches from the end of the plate and 4 inches from the middle, making the three spaces on the left 3, 4 and 5 inches respectively, and the others 6 inches, the plan of the beam will appear as in the figure. This gives more than double the number required between the end of the plate E and C, and plenty between C and M.

In case more than one cover plate is used, there must be rivets enough between the ends of the first and the second plate to take up the tension in the first plate.

The number is found precisely as above.

In the compression flange, the cover plate between any two consecutive rivets forms a solid rectangular column.

And hence the rivets should not be so far apart as to allow of any material amount of long column flexure.

The pitch of the rivets should probably not be more than about 20 times the thickness of the plate.

The reaction at the ends of the beam is 30,000 pounds.

The transverse section of the web is $28 \times \frac{3}{8} = 10.5$ square inches, the shearing resistance of which is $10.5 \times 8{,}000 = 84{,}000$ pounds, or nearly three times the amount required.

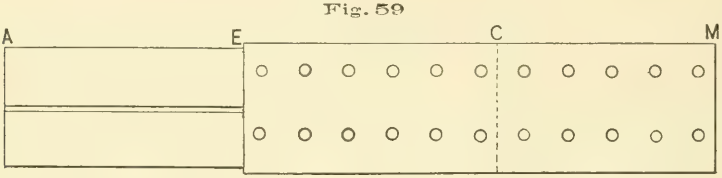
The upward pressure of 30,000 pounds at the end of the beam must also be provided for.

For this we will rivet two $3'' \times 2\frac{1}{2}'' \times \frac{3}{8}''$ angle irons to the web, one on each side, the 3'' legs lying against the web.

The area of the cross section of these two angle irons is 4 square inches, which is abundant to take up a compression of 30,000 pounds.

Since the bearing capacity of a $\frac{3}{4}''$ rivet is 4,220 pounds, we will require $30{,}000 \div 4{,}220 = 8$ such rivets to transfer the strain from the angles to the web; 11 rivets are used, as shown in the figure.

Fig. 59




It is important in such cases as this to secure a firm bearing of the lower ends of the vertical angle irons upon the flanges of the angle irons of the lower flange, in order that the former may take up the reaction, and prevent the crushing of the web plate.

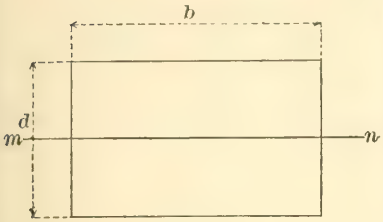
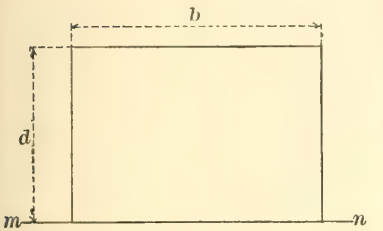
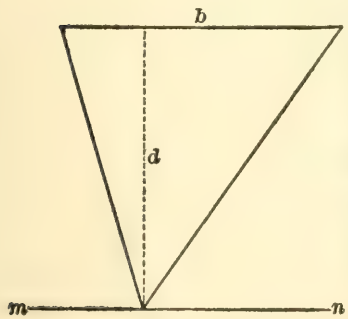
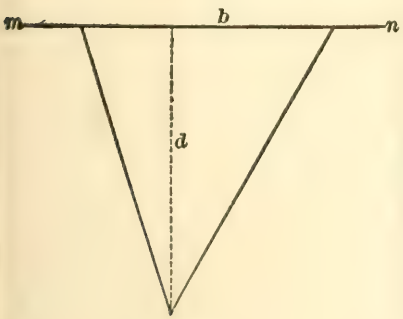
Stiffening angles similar to those used at the ends should be riveted to the web at C and D.

Since riveted work is never perfect, and since, too, the strains in the flanges are along the lines of rivet holes, which do not coincide with the *center* of *forces* on the angles, it is plain that there must be some strain and distortion of the flanges, not provided for in the computation.

It is well, therefore, to use an abundance of rivets.

Taking the effective depth at 28 inches, which it is customary to do, and which, we are assured, leads to "no essential error," we find the moment of resistance

TABLE I.—MOMENTS OF INERTIA AND RESISTANCE.

| Form of Section. | Moment of Inertia I. | Moment of Resistance $\frac{I}{d}$ |
|---|---|---|
|   Fig. 1 | $\frac{1}{12}bd^3 = \frac{1}{12}Ad^2$. | $\frac{1}{6}bd^2 = \frac{1}{6}Ad$. |
|   Fig. 2 | $\frac{1}{3}bd^3 = \frac{1}{3}Ad^2$. | $\frac{1}{3}bd^2 = \frac{1}{3}Ad$. |
|   Fig. 3 | $\frac{1}{4}bd^3$ | $\frac{1}{6}bd^2$ |
|   Fig. 4 | $\frac{1}{12}bd^3$. | $\frac{1}{12}bd^2$ |

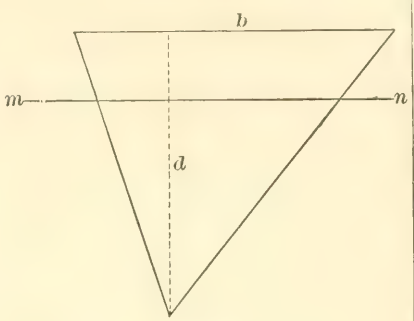
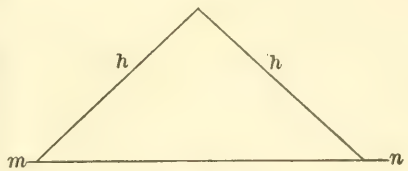
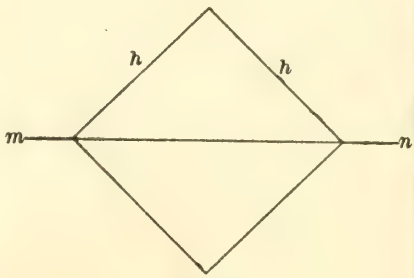
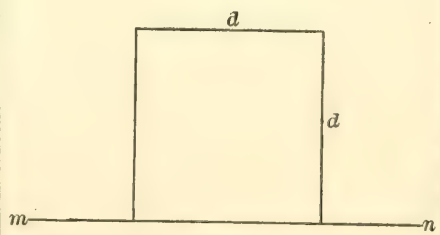
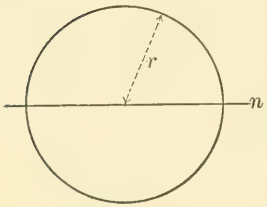
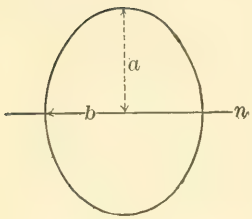
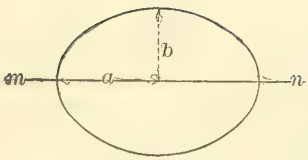
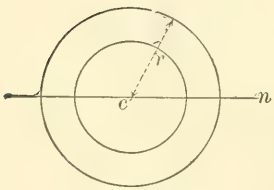
| Form of Section. | Moment of Inertia I. | Moment of Resistance $\frac{I}{d}$ |
|---|---|---|
|   Fig. 5 | $\frac{1}{36}bd^3$ | $\frac{1}{24}bd^2$ |
|   Fig. 6 | $.0417h^4$ | $.059h^3$ |
|   Fig. 7 | $.0834h^4$ | $.1179h^3$ |
|   Fig. 8 | $\frac{1}{3}d^4 = \frac{1}{3}Ad^2$ | $\frac{1}{3}d^3 = \frac{1}{3}Ad$ |

TABLE I.—Continued.

| Form of Section. | Moment of Inertia I. | Moment of Resistance $\frac{I}{d}$ |
|---|---|---|
|   Fig. 9 | $\frac{1}{4}\pi r^4$ | $\frac{1}{4}\pi r^3$ |
|   Fig. 10 | $\frac{1}{4}\pi a^3 b$ | $\frac{1}{4}\pi a^2 b$ |
|   Fig. 11 | $\frac{1}{4}\pi b^3 a$ | $\frac{1}{4}\pi b^2 a$ |
|   Fig. 12 | $\frac{1}{4}\pi(r^4 - r_1^4)$ | $\frac{\frac{1}{4}\pi(r^4 - r_1^4)}{r}$ |

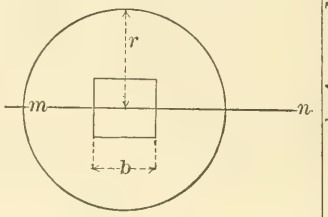
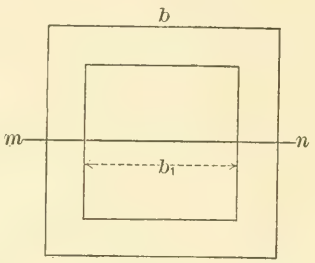
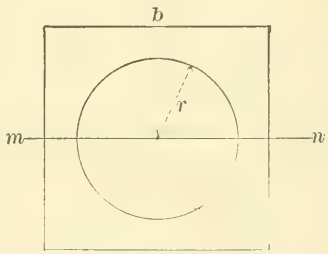
| Form of Section. | Moment of Inertia I. | Moment of Resistance $\frac{I}{d}$ |
|---|---|---|
|   Fig. 13 | $\frac{1}{4}\pi r^4 - \frac{1}{12}b^4$ | $\frac{\frac{1}{4}\pi r^4 - \frac{1}{12}b^4}{r}$ |
|   Fig. 14 | $\frac{1}{12}(b^4 - b_1^4)$ | $\frac{\frac{1}{12}(b^4 - b_1^4)}{b}$ |
|   Fig. 15 | $\frac{1}{12}b^4 - \frac{1}{4}\pi r^4$ | $\frac{\frac{1}{12}b^4 - \frac{1}{4}\pi r^4}{b}$ |

TABLE I.—Continued.

| Form of Section. | Moment of Inertia I. | Moment of Resistance $\frac{I}{d}$ |
|---|---|---|
|  Fig. 16 | $a\left(d^2-2dr+\frac{5r^2}{4}\right)$ | $a\left(d-2r+\frac{5r^2}{4d}\right)$ $=a\left(d_1+\frac{5r^2}{4d}\right)$ |
|  Fig. 17 | $a\left(d^2-2dr+\frac{5r^2}{4}\right)$ | $a\left(d-2r+\frac{5r^2}{4d}\right)$ $=a\left(d_1+\frac{5r^2}{4d}\right)$ |
|  Fig. 18 | $a\left(d^2-1.15dr+\frac{2r^2}{5}\right)$ | $a\left(d-1.15r+\frac{2r^2}{5d}\right)$ |
|  Fig. 19 | $a\left(d^2-.848dr+\frac{r^2}{4}\right)$ | $a\left(d-.848r+\frac{r^2}{4d}\right)$ |

| Form of Section. | Moment of Inertia I. | Moment of Resistance $\frac{I}{d}$ |
|---|---|---|
|  Fig. 20 | $\frac{5d^4}{9}=0.9623\,d^4$ $=\frac{5}{16}r^4\sqrt{3}$ $=0.5413r^4$ | $0.9623d^3$ |
|  Fig. 21 | $0.5413d^4$ $=0.5413r^4$ | $0.5413d^3$ |
|  Fig. 22 | $\frac{1+2\sqrt{2}}{6}r^4$ $=0.6381r^4$ $=0.8761d^4$ | $0.8761d^3$ |
|  Fig. 23 | $0.8761(d^4-d_1{}^4)$ | $\frac{0.8761(d^4-d_1{}^4)}{d}$ |

$=10{,}000\times7.5\times28=2{,}100{,}000.$

Now $(2{,}100{,}000-1{,}883{,}000)\div1{,}883{,}000=.115$, which shows an error of $11\frac{1}{2}\%$.

The error committed by assuming the effective depth to be equal to that of the web plate is greater without than with flange plates; it increases as $h$ increases compared with D.

It is usually between 10 and 20%, giving an average of perhaps 15%.

The distortion spoken of above is greater with than without cover plates; hence it is better to use cover plates sparingly, even at the sacrifice of some extra material at the ends of the angles.

It is generally better, too, to use one cover plate for each flange than two or more, even though the one requires more material than the two; for, in the first place, the heavy plate between two consecutive rivets will resist far more bending, as a column, than two plates of the same combined thickness; and, again, many more rivets are required with two plates than with one.

We may now compute the weight of the beam.

We have—

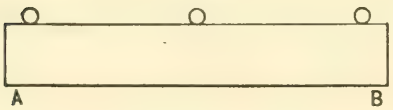
| | Pounds. |
|---|---|
| 1 web plate, $16'\times28''\times\frac{3}{8}''\times\frac{10}{3}$ | 560 |
| 4 angles, $4\times16'\times10.4$ | 666 |
| 2 cover plates, $2\times10\times8''\times\frac{5}{16}''\times\frac{10}{3}$ | 167 |
| 8 stiffening angles, $8\times3\frac{1}{2}'\times6.7$ sq. ins. | 121 |
| 8 filling plates, $8\times3\frac{3}{16}'\times3''\times\frac{1}{2}''\times\frac{10}{3}$ | 73 |
| Rivet heads (say) | 33 |
| | 1,620 |

**or 101 pounds per foot.**

**The weight of the beam exceeds the estimate by a few pounds only.**

**Should we dispense with the filling plates, which is often done, but not advisable, the weight of the beam would fall a little short of the estimate.**

Fig. 60




The above design will apply equally well to the track stringer, or to any track stringer or plate girder.

In case of the above track stringer, for example, the greatest reaction at each end is $\frac{24{,}000\times3}{2}=36{,}000$ pounds.

The moment at the center of the stringer in inch pounds is

$$36{,}000\times8\times12-24{,}000\times7\times12=1{,}440{,}000.$$

The moment of resistance of two 15″ light Carnegie eye beams is, by Carnegie or our Table above,

$$2\times70.6\times10{,}000=1{,}412{,}000.$$

This shows that two eye beams slightly heavier than the above would be sufficient for track stringers for the assumed load.

### Wooden Beams.

The following Table gives the safe load, uniformly distributed, for rectangular oak or white or yellow pine beams, for a maximum fiber strain of 10,000 pounds per square inch. The table covers the sizes in general use. Observing, however, that the strength varies as the the thickness and as the square of the depth, the strength of any size may be easily obtained from some tabular size. Thus, a beam $2\times16$ will carry four times the load that one $2\times8$ will carry, or two-thirds the load that a beam $3\times16$ will carry.

Observing, too, that

$9^2=8^2+4^2$ nearly, $10^2=8^2+6^2$

$18^2=16^2+8^2$ nearly, and

$20^2=16^2+12^2$, etc., etc.

Table II.

Size of Beam.

| Length in ft. | 2×4 | 2×6 | 2×8 | 2×10 | 2×12 | 3×12 | 3×14 | 3×16 |
|---|---|---|---|---|---|---|---|---|
| 6 | 593 | 1333 | 2370 | 3704 | 5333 | 8000 | 10889 | 14222 |
| 7 | 508 | 1143 | 2032 | 3175 | 4571 | 6857 | 9333 | 12190 |
| 8 | 444 | 1000 | 1778 | 2778 | 4000 | 6000 | 8167 | 10667 |
| 9 | 395 | 889 | 1580 | 2469 | 3556 | 5333 | 7259 | 9481 |
| 10 | 356 | 800 | 1422 | 2222 | 3200 | 4800 | 6533 | 8533 |
| 11 | 323 | 727 | 1293 | 2020 | 2909 | 4364 | 5939 | 7758 |
| 12 | 296 | 667 | 1185 | 1852 | 2667 | 4000 | 5444 | 7111 |
| 13 | 274 | 615 | 1094 | 1709 | 2462 | 3692 | 5026 | 6564 |
| 14 | 254 | 571 | 1016 | 1587 | 2286 | 3429 | 4667 | 6095 |
| 15 | 237 | 533 | 948 | 1481 | 2133 | 3200 | 4356 | 5689 |
| 16 | 222 | 500 | 889 | 1389 | 2000 | 3000 | 4083 | 5333 |
| 17 | 209 | 471 | 837 | 1307 | 1882 | 2824 | 3843 | 5020 |
| 18 | 198 | 444 | 790 | 1235 | 1778 | 2667 | 3630 | 4741 |
| 19 | 187 | 421 | 749 | 1170 | 1684 | 2526 | 3439 | 4491 |
| 20 | 178 | 400 | 711 | 1111 | 1600 | 2400 | 3267 | 4267 |
| 21 | 169 | 381 | 677 | 1058 | 1524 | 2286 | 3111 | 4063 |
| 22 | 162 | 364 | 646 | 1010 | 1455 | 2182 | 2970 | 3879 |
| 23 | 155 | 348 | 618 | 966 | 1391 | 2087 | 2841 | 3710 |
| 24 | 148 | 333 | 593 | 926 | 1333 | 2000 | 2722 | 3556 |
| 25 | 142 | 320 | 569 | 889 | 1280 | 1920 | 2613 | 3413 |

TABLE III.

| Distance between supports in ft. | Effective Depth of Girder in Inches. | | | | | | |
|---|---|---|---|---|---|---|---|
| | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 10 | .125 | .107 | .094 | .083 | .075 | .068 | .062 |
| 11 | .137 | .118 | .103 | .092 | .082 | .075 | .069 |
| 12 | .150 | .129 | .112 | .100 | .090 | .082 | .075 |
| 13 | .162 | .139 | .122 | .108 | .097 | .089 | .081 |
| 14 | .175 | .150 | .131 | .117 | .105 | .095 | .087 |
| 15 | .187 | .161 | .141 | .125 | .112 | .102 | .094 |
| 16 | .200 | .171 | .150 | .133 | .120 | .109 | .100 |
| 17 | .212 | .182 | .159 | .142 | .127 | .116 | .106 |
| 18 | .225 | .193 | .169 | .150 | .135 | .123 | .112 |
| 19 | .237 | .204 | .178 | .158 | .142 | .130 | .119 |
| 20 | .250 | .214 | .187 | .167 | .150 | .136 | .125 |
| 21 | .262 | .225 | .197 | .175 | .157 | .143 | .131 |
| 22 | .275 | .236 | .206 | .183 | .165 | .150 | .137 |
| 23 | .287 | .246 | .216 | .192 | .172 | .157 | .144 |
| 24 | .300 | .257 | .225 | .200 | .180 | .164 | .150 |
| 25 | .312 | .268 | .234 | .208 | .187 | .170 | .156 |
| 26 | .325 | .279 | .244 | .217 | .195 | .177 | .162 |
| 27 | .337 | .289 | .253 | .225 | .202 | .184 | .169 |
| 28 | .350 | .300 | .262 | .233 | .210 | .191 | .175 |
| 29 | .362 | .311 | .272 | .242 | .217 | .198 | .181 |
| 30 | .375 | .321 | .281 | .250 | .225 | .205 | .187 |

| Distance between supports in ft. | Effective Depth of Girder in Inches. | | | | | | |
|---|---|---|---|---|---|---|---|
| | 26 | 28 | 30 | 32 | 34 | 36 | 38 |
| 10 | .058 | .054 | .050 | .047 | .044 | .042 | .039 |
| 11 | .063 | .059 | .055 | .052 | .049 | .046 | .043 |
| 12 | .069 | .064 | .060 | .056 | .053 | .050 | .047 |
| 13 | .075 | .070 | .065 | .061 | .058 | .054 | .051 |
| 14 | .081 | .075 | .070 | .066 | .062 | .058 | .055 |
| 15 | .087 | .080 | .075 | .070 | .066 | .062 | .059 |
| 16 | .092 | .086 | .080 | .075 | .071 | .067 | .063 |
| 17 | .098 | .091 | .085 | .080 | .075 | .071 | .067 |
| 18 | .104 | .096 | .090 | .084 | .079 | .075 | .071 |
| 19 | .110 | .102 | .095 | .089 | .084 | .079 | .075 |
| 20 | .115 | .107 | .100 | .094 | .088 | .083 | .079 |
| 21 | .121 | .112 | .105 | .098 | .093 | .087 | .083 |
| 22 | .127 | .118 | .110 | .103 | .097 | .092 | .087 |
| 23 | .133 | .123 | .115 | .108 | .101 | .096 | .091 |
| 24 | .138 | .129 | .120 | .112 | .106 | .100 | .095 |
| 25 | .144 | .134 | .125 | .117 | .110 | .104 | .099 |
| 26 | .150 | .139 | .130 | .122 | .115 | .108 | .103 |
| 27 | .156 | .145 | .135 | .127 | .119 | .112 | .107 |
| 28 | .162 | .150 | .140 | .131 | .124 | .117 | .110 |
| 29 | .167 | .155 | .145 | .136 | .128 | .121 | .114 |
| 30 | .173 | .161 | .150 | .141 | .132 | .125 | .118 |
| 31 | .179 | .166 | .155 | .145 | .137 | .129 | .122 |
| 32 | .185 | .171 | .160 | .150 | .141 | .133 | .126 |
| 33 | .190 | .177 | .165 | .155 | .146 | .137 | .130 |
| 34 | .196 | .182 | .170 | .159 | .150 | .142 | .134 |
| 35 | .202 | .187 | .175 | .164 | .154 | .146 | .138 |
| 36 | .208 | .193 | .180 | .169 | .159 | .150 | .142 |
| 37 | .213 | .198 | .185 | .173 | .163 | .154 | .146 |
| 38 | .219 | .204 | .190 | .178 | .168 | .158 | .150 |
| 39 | .225 | .209 | .195 | .183 | .172 | .162 | .154 |
| 40 | .231 | .214 | .200 | .188 | .176 | .167 | .158 |

TABLE IV.

Shearing, Bending Moment and Bearing Value of Rivets. Maximum fiber strain for bending 17,500 pounds per square inch.

| Diameter of Rivet in Ins. | Area of Rivet. | Single Shear at 7500 lbs. per sq. inch. | Bending Moments in inch pounds. | Bearing value for different thicknesses of plate at 15,000 lbs. per sq. inch. (=Diameter of Rivet×thickness of plate×15,000 lbs.) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1/4″ | 5/16″ | 3/8″ | 7/16″ | 1/2″ | 9/16″ | 5/8″ | 11/16″ | 3/4″ | 13/16″ | 7/8″ | |
| 5/8 | 1104 | 828 | 91 | 1410 | | | | | | | | | | | |
| 11/16 | 1503 | 1130 | 144 | 1640 | 2050 | | | | | | | | | | |
| 3/4 | 1963 | 1470 | 215 | 1880 | 2340 | 2810 | | | | | | | | | |
| 13/16 | 2485 | 1860 | 306 | 2110 | 2640 | 3160 | 3690 | | | | | | | | |
| 7/8 | 3068 | 2300 | 429 | 2340 | 2930 | 3520 | 4100 | | | | | | | | |
| 15/16 | 3712 | 2780 | 558 | 2580 | 3220 | 3870 | 4510 | 5160 | | | | | | | |
| 1 | 4418 | 3310 | 725 | 2810 | 3520 | 4220 | 4920 | 5630 | 6330 | | | | | | |
| 1 1/16 | 5185 | 3890 | 921 | 3050 | 3810 | 4570 | 5330 | 6090 | 6860 | 7620 | | | | | |
| 1 1/8 | 6013 | 4510 | 1151 | 3280 | 4100 | 4920 | 5740 | 6560 | 7380 | 8200 | | | | | |
| 1 3/16 | 6903 | 5180 | 1415 | 3520 | 4390 | 5270 | 6150 | 7030 | 7910 | 8790 | 9670 | | | | |
| 1 | 7854 | 5890 | 1718 | 3750 | 4690 | 5620 | 6560 | 7500 | 8440 | 9380 | 10310 | 11250 | | | |
| 1 1/8 | 8866 | 6650 | 2060 | 3980 | 4980 | 5980 | 6970 | 7970 | 8960 | 9960 | 10960 | 11950 | 12950 | | |
| 1 1/4 | 9940 | 7460 | 2447 | 4220 | 5270 | 6330 | 7380 | 8440 | 9490 | 10550 | 11600 | 12660 | 13710 | 14770 | |
| 1 3/8 | 1.1075 | 8310 | 2877 | 4450 | 5570 | 6680 | 7790 | 8910 | 10020 | 11130 | 12250 | 13360 | 14470 | 15590 | |

We see that a beam 9 inches in depth is but a trifle stronger than two beams of the same width, 8 and 4 inches in depth respectively. The same may be said of a beam 18 inches in depth compared with two beams 16 and 8 inches in depth. A beam 10 inches in depth has just the strength of two others of the same width, 8 and 6 inches in depth respectively; and the same is true of a beam 20 inches in depth compared with two others 16 and 12 inches in depth.

TABLE V.

Bearing Value of Pins for one Inch Thickness of Plate.

| Diameter of Pin. Inches. | Area of Pin. Sq. inches. | Bearing Value at 12500 lbs. per sq. inch. lbs. | Bearing Value at 15000 lbs. per sq. inch. lbs. |
|---|---|---|---|
| 1 | .785 | 12500 | 15000 |
| 1 1/8 | .994 | 14100 | 16900 |
| 1 1/4 | 1.227 | 15000 | 18800 |
| 1 3/8 | 1.485 | 17200 | 20600 |
| 1 1/2 | 1.767 | 18800 | 22500 |
| 1 5/8 | 2.074 | 20300 | 24400 |
| 1 3/4 | 2.405 | 21900 | 26300 |
| 1 7/8 | 2.761 | 23400 | 28100 |
| 2 | 3.142 | 25000 | 30000 |
| 2 1/8 | 3.547 | 26600 | 31900 |
| 2 1/4 | 3.976 | 28100 | 33800 |
| 2 3/8 | 4.430 | 29700 | 35600 |
| 2 1/2 | 4.909 | 31300 | 37500 |
| 2 5/8 | 5.412 | 32800 | 39400 |
| 2 3/4 | 5.940 | 34400 | 41300 |
| 2 7/8 | 6.492 | 35900 | 43100 |
| 3 | 7.069 | 37500 | 45000 |
| 3 1/8 | 7.670 | 39100 | 46900 |
| 3 3/8 | 8.946 | 42200 | 50600 |
| 3 5/8 | 10.32 | 45500 | 54400 |
| 3 7/8 | 11.79 | 48400 | 58100 |
| 4 1/8 | 13.36 | 51600 | 61900 |
| 4 3/8 | 15.03 | 54700 | 65600 |
| 4 5/8 | 16.80 | 57800 | 69400 |
| 4 7/8 | 18.67 | 60900 | 73100 |
| 5 1/8 | 20.63 | 64100 | 76900 |
| 5 3/8 | 22.69 | 67200 | 80600 |
| 5 5/8 | 24 85 | 70300 | 84400 |
| 5 7/8 | 27.11 | 73400 | 88100 |
| 6 1/8 | 29.46 | 76600 | 91900 |
| 6 3/8 | 31.92 | 79700 | 95600 |
| 6 5/8 | 34.47 | 82800 | 99400 |
| 6 7/8 | 37.12 | 85900 | 103100 |

TABLE VI.

Maximum Bending Moments to be allowed on Pins for Maximum Fiber Strains of 15000, 20000 and 22500 lbs. per square inch.

| Diameter of Pin in Inches. | Moment for S=15000. Lbs. in. | Moment for S=20000. Lbs. in. | Moment for S=22500. Lbs. in. |
|---|---|---|---|
| 1 | 1470 | 1960 | 2210 |
| 1 1/8 | 2100 | 2800 | 3140 |
| 1 1/4 | 2880 | 3830 | 4310 |
| 1 3/8 | 3830 | 5100 | 5740 |
| 1 1/2 | 4970 | 6630 | 7460 |
| 1 5/8 | 6320 | 8430 | 9480 |
| 1 3/4 | 7890 | 10500 | 11800 |
| 1 7/8 | 9710 | 12900 | 14600 |
| 2 | 11800 | 15700 | 17700 |
| 2 1/8 | 14100 | 18800 | 21200 |
| 2 1/4 | 16800 | 22400 | 25200 |
| 2 3/8 | 19700 | 26300 | 29600 |
| 2 1/2 | 23000 | 30700 | 34500 |
| 2 5/8 | 26600 | 35500 | 40000 |
| 2 3/4 | 30600 | 40800 | 45900 |
| 2 7/8 | 35000 | 46700 | 52500 |
| 3 | 39800 | 53000 | 59600 |
| 3 1/8 | 44900 | 59900 | 67400 |
| 3 1/4 | 50400 | 67400 | 75800 |
| 3 3/8 | 56600 | 75500 | 84900 |
| 3 1/2 | 63100 | 84200 | 94700 |
| 3 5/8 | 70100 | 93500 | 105200 |
| 3 3/4 | 77700 | 103500 | 116500 |
| 3 7/8 | 85700 | 114200 | 128500 |
| 4 | 94200 | 125700 | 141400 |
| 4 1/8 | 103400 | 137800 | 155000 |
| 4 1/4 | 113000 | 150700 | 169600 |
| 4 3/8 | 123300 | 164400 | 185000 |
| 4 1/2 | 134200 | 178900 | 201300 |
| 4 5/8 | 145700 | 194300 | 218500 |
| 4 3/4 | 157800 | 210400 | 236700 |
| 4 7/8 | 170600 | 227500 | 255900 |
| 5 | 184100 | 245400 | 276100 |
| 5 1/8 | 198200 | 264300 | 297300 |
| 5 1/4 | 213100 | 284100 | 319600 |
| 5 3/8 | 228700 | 304900 | 343000 |
| 5 1/2 | 245000 | 326700 | 367500 |
| 5 5/8 | 262100 | 349500 | 393100 |
| 5 3/4 | 280000 | 373300 | 419900 |
| 5 7/8 | 298600 | 398200 | 447900 |
| 6 | 318100 | 424100 | 477100 |
| 6 1/8 | 338400 | 451200 | 507600 |
| 6 1/4 | 359.00 | 479400 | 539300 |
| 6 3/8 | 381500 | 508700 | 572300 |
| 6 1/2 | 404400 | 539200 | 606600 |
| 6 5/8 | 428200 | 570900 | 642300 |
| 6 3/4 | 452900 | 603900 | 679400 |
| 6 7/8 | 478500 | 6380 0 | 717800 |

### Plate Girders.

Table III. gives coefficients for determining the area required in flanges, allowing 10,000 pounds fiber strain per square inch of gross section.

The Table gives, opposite the length and under the effective depth, the area required for a distributed load of 1,000 pounds. Hence, to find the area required for a given load, multiply the co-efficient by the load in pounds and divide by 1,000.

For simplicity, the total depth may be taken for the effective depth; but this will of course give too large a co-efficient and too small an area. The error thus committed is approximately equal to the resistance of the web; and thus we see that, taking the total in place of the effective depth, virtually supposes the web effective in resisting longitudinal strains, though professedly ignoring it for such a purpose.

### Explanation of Tables IV., V. and VI.

Rivets must be proportioned for transmitting the entire stress from one plate or group of plates, to another, taking into consideration the shearing and bending resistances, and the bearing surfaces. The requirements for bearing are frequently neglected, notwithstanding such requirements, except for the smaller rivets, frequently determine the number of rivets to be used. The bending moments of rivets usually determine the number of the smaller sized rivets to be used. For example, the bearing value of a $\frac{3}{4}''$ rivet on a $\frac{3}{8}''$ plate is 4,220 pounds, while the double shear of the same is 6,620 pounds. Examples illustrating bending will be given subsequently. If in any given case the number of rivets required to furnish sufficient bearing, much exceeds the number for shearing or bending, it may be advisable to increase the thickness of the plate for the purpose of decreasing the number of rivets.

Pins must also be proportioned for shearing, bending and bearing; but one of the two latter determines, in almost every case, the size required.

Where groups of bars are connected to the same pin, as in the lower chords of truss bridges, the bars should be of a proper size, and be properly placed so as to make the bending strain, and consequently the size of the pin, as small as possible.

*Examples.*—Required the thickness of metal in the top chord of a bridge that will give sufficient bearing area for $3\frac{1}{8}''$ pin having to transmit a pressure of 60,000 pounds, the allowable pressure per inch of diameter of pin for one inch thickness of plate being 12,500 pounds.

The bearing value of a $3\frac{1}{8}''$ pin for $1''$ thickness of plate $= 39{,}100$ pounds; therefore the thickness required $= \frac{60000}{39100} = 1\frac{1}{2}''$ nearly. Hence each of the two plates in the chord should be fully $\frac{3}{4}''$ thick.

The tension in the lower chord of a Pratt truss bridge, at the foot of the hip vertical, is 60,500 pounds. The chord on either side of the joint is formed of two bars $3\frac{1}{2}'' \times \frac{7}{8}''$. what is the diameter of the required pin, allowing a fiber strain of 15,000 pounds?

The pull on each of a pair of bars (two bars "packed" close together in adjacent panels) is 30,250 pounds. The lever arm of this pull is the distance between centers of the bars $= \frac{7}{8}''$. Hence the moment is $30{,}250 \times \frac{7}{8} = 26{,}470$, which calls for a pin $2\frac{5}{8}''$ in diameter.

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The Chif Engineer and Inspector of Public Works in Java, M. van Geûns, has lately been on a journey through that and the neighboring islands, of which he has published an account. He speaks of the various Javan volcanoes, of which much has been heard lately, and says that since the eruption of Krakatao in 1883, the people live in comparative quiet. But this calm is only apparent, for volcanic eruptions, always numerous, are incessant. The volcanoes on the Island of Java itself manifest everywhere great activity, but not so as to produce a serious cataclysm. Smeroc, which is the heighest mountain in the island, and its neighbors Brômo and Lamonyon, are active from time to time. In 1855, for example, Smeroc overwhelmed plantations and villages on its side with eruptive matter. Merapi, in the center of the island, shows constant signs of life; lava is constantly flowing from it, smoke and steam are almost always visible at its summit, so that it is one of the active volcanoes of the world. M. van Geûns reports another curious phenomenon. After a period of extreme drought, continued rains have inundated one part of the country, while there is an absolute want of water in other places which should have it in abundance. This anomaly is attributed to the monsoons which blow irregularly, and which cause more anxiety to the Javanese than their volcanoes.

# THE FLEXURE AND RESISTANCE OF LONG COLUMNS.

By L. M. HOSKINS, University of Wisconsin.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

In discussions of the flexure of columns, it is usual to employ as the differential equation of the elastic curve the form

$$\frac{d^2y}{dx^2}=\frac{M}{EI}, \qquad (1)$$

M being the moment of the applied load with reference to any point of the central line of the column, whose co-ordinates are $x$ and $y$, E the coefficient of elasticity of the material, and I the principal moment of inertia of the cross-section. If we accept the "common theory" of flexure, this equation is only approximately true. The differential coefficient $\frac{d^2y}{dx^2}$ is used instead of the quantity $\frac{1}{\rho}$, the reciprocal of the radius of curvature, the true value being

$$\frac{\frac{d^2y}{dx^2}}{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{\frac{3}{2}}}.$$

And even if the correct value of $\frac{1}{\rho}$ be used, the equation is strictly true only when all applied forces are transverse, and is therefore *not* strictly true in the case of a column.

A differential equation that is applicable to *any* condition of loading may be deduced as follows:

Taking any column, or beam, of uniform cross-section, acted upon by any forces whatever, let P denote the sum of all external longitudinal forces acting at one side of a given section, compressive forces being assumed positive; M the moment of all forces at one side of the section with reference to its central axis; $z'$ the distance of the neutral from the central axis; $z$ the distance of any point of the section from the central axis; $\rho$ the radius of curvature of a fiber at the central axis; $\rho_1$ the radius of curvature of a fiber at the neutral axis; A the area of the cross-section; I the principal moment of inertia of the cross-section; $x$ and $y$ the co-ordinates of any point of the central line of the column. Since, by the theory of flexure, the fibers bend into parallel curves, it is evident that $\rho_1=\rho-z'$.

The shortening per unit length of any fiber at distance $z$ from the central axis ($z-z'$ from the *neutral* axis) is

$$\frac{z-z'}{\rho_1}, \text{ or } \frac{z-z'}{\rho-z'};$$

and the unit compressive stress on it is

$$\frac{E(z-z')}{\rho-z'}.$$

The stress on the element of area $dA$ is

$$\frac{E(z-z')dA}{\rho-z'},$$

and the sum of such stresses for the whole section is

$$\frac{\Sigma E(z-z')dA}{\rho-z'}=-\frac{EAz'}{\rho-z'}.$$

Hence, for equilibrium,

$$-\frac{EAz'}{\rho-z'}=P$$

or

$$z'=-\frac{\frac{P}{A}\rho}{E-\frac{P}{A}}.$$

Again, the moment of any stress

$$\frac{E(z-z')dA}{\rho-z'}$$

with reference to the central axis of the section is

$$\frac{Ez(z-z')dA}{\rho-z'},$$

and the sum of such moments for the whole section is

$$\frac{\Sigma E(z^2-zz')dA}{\rho-z'}=\frac{EI}{\rho-z'}.$$

Hence, for equilibrium,

$$\frac{EI}{\rho-z'}=M,$$

or

$$z'=\rho-\frac{EI}{M}.$$

Equating the two values found for $z'$, gives, after reducing,

$$\frac{1}{\rho}=\frac{M}{\left(E-\frac{P}{A}\right)I} \qquad (2)^*$$

Comparing equations (1) and (2), it is seen that the use of the former involves not only the usual substitution of an approximate value for $\frac{1}{\rho}$, but also the assumption that $\frac{P}{A}$ may be neglected in comparison with E. Let us see what change this assumption introduces into Euler's formula for long columns, taking up later the discussion of equation (2). using the accurate value for $\frac{1}{\rho}$. It may be expected that in the case of the ordinary materials, and within the limits of applicability of the equation, the change will be of little importance. For since perfect elasticity is assumed in deducing the equation, it is true only within the elastic limit; and within that limit the ratio of $\frac{P}{A}$ to E is very small.

For the case of round ends, we have $M=-Py$, and (2) takes the form

$$\frac{1}{\rho}=-\frac{Py}{\left(E-\frac{P}{A}\right)I},$$

or approximately,

$$\frac{d^2y}{dx^2}=-\frac{Py}{\left(E-\frac{P}{A}\right)I}; \qquad (3)$$

while (1) becomes

$$\frac{d^2y}{dx^2}=-\frac{Py}{EI} \qquad (4)$$

For the case of fixed ends, $M=M'-Py$, $M'$ being the restraining moment at the end, and we have instead of (3) and (4) the equations

$$\frac{d^2y}{dx^2}=-\frac{Py-M'}{\left(E-\frac{P}{A}\right)I} \qquad (5)$$

$$\frac{d^2y}{dx^2}=-\frac{Py-M'}{EI} \qquad (6)$$

Without carrying out the integrations, it is evident that the results derived from (3) and (5) may be obtained from those derived from (4) and (6) by the substitution of $E-\frac{P}{A}$ for E. From (4) and (6) may be derived the well-known formulæ

$$\frac{P}{A}=\frac{E}{\frac{1}{\pi^2}\cdot\frac{l^2}{r^2}} \qquad (7)$$

$$\frac{P}{A}=\frac{E}{\frac{1}{4\pi^2}\cdot\frac{l^2}{r^2}} \qquad (8)$$

$r$ being the principal radius of gyration of the cross-section. Putting $E-\frac{P}{A}$ for E gives, after reducing,

$$\frac{P}{A}=\frac{E}{1+\frac{1}{\pi^2}\cdot\frac{l^2}{r^2}} \qquad (9)$$

$$\frac{P}{A}=\frac{E}{1+\frac{1}{4\pi^2}\cdot\frac{l^2}{r^2}} \qquad (10)$$

A comparison of (9) and (10) with (7) and (8) shows that the differences are important only for small values of $\frac{l}{r}$. But these will, for ordinary materials,

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* The following method of deriving equation (2) may seem simpler: In case there is no longitudinal loading, the reasoning is as follows: The strain per unit length on any fiber is $\frac{z}{\rho}$; the corresponding unit stress is $\frac{Ez}{\rho}$; the stress on an area $dA$ is $\frac{Ezd\mathrm{A}}{\rho}$; its moment about the central also the neutral) axis of the section is $\frac{Ez^2d\mathrm{A}}{\rho}$; and the sum of all such moments for the section is

$$M=\frac{E}{\rho}\Sigma z^2d\mathrm{A}=\frac{EI}{\rho}.$$

In this reasoning, the unit strain on any fiber is the strain per unit *of the length before bending*. But if there is a longitudinal compressive force P, each fiber is strained before bending to the fraction $\frac{E-\frac{P}{A}}{E}$ of its original length. Hence the actual unit strain due to bending is $\frac{E-\frac{P}{A}}{E}$ of $\frac{z}{\rho}$, and the correponding unit stress is $\frac{\left(E-\frac{P}{A}\right)z}{\rho}$. This change gives for the final result

$$M=\frac{E-\frac{P}{A}}{\rho}\Sigma z^2d\mathrm{A}=\frac{\left(E-\frac{P}{A}\right)I}{\rho},$$

which is identical with equation (2).

correspond to values of $\frac{P}{A}$ beyond the elastic limit. The smallest values of $\frac{l}{r}$ for which (9) and (10) are applicable may be found, for any given material, by substituting for $\frac{P}{A}$ the compressive elastic limit, and solving for $\frac{l}{r}$. Thus, if Q is the elastic limit, the limiting value of $\frac{l}{r}$ is for round-ended columns,

$$\frac{l}{r}=\pi\sqrt{\frac{E-Q}{Q}} \qquad (11)$$

and for fixed-ended columns,

$$\frac{l}{r}=2\pi\sqrt{\frac{E-Q}{Q}} \qquad (12)$$

Equations (7) and (8), or (9) and (10), indicate that $\frac{P}{A}$ is independent of the amount of bending. The conclusion is that the value found for $\frac{P}{A}$ is the greatest resistance of the column. For if the load be increased above this value, no condition of bending can cause a resisting moment equal to the bending moment.

It is now proposed to take up the solution of equation (2), using the accurate value of $\frac{1}{\rho}$.

For the case of round ends, (2) takes the form

$$\frac{\frac{d^2y}{dx^2}}{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{\frac{3}{2}}}=-Ly \qquad (13)$$

where $$L=\frac{\frac{P}{A}}{\left(E-\frac{P}{A}\right)r^2}$$

The solution of this equation in terms of elliptic integrals may be effected as follows:

Multiplying through by $\frac{dy}{dx}$, and integrating,

$$\frac{2}{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{\frac{1}{2}}}=2-L(y_1^2-y^2),$$

where $y_1$ is the value of $y$ at the middle of the column. Reducing,

$$dx=\frac{[2-L(y_1^2-y^2)]dy}{\sqrt{4L(y_1^2-y^2)-L^2(y_1^2-y^2)^2}} \qquad (14)$$

Putting $\frac{y}{y_1}=\cos\varphi$, and $\frac{Ly_1^2}{4}=k^2$,

$$dx=\frac{1}{\sqrt{L}}\left(\frac{d\varphi}{\sqrt{1-k^2\sin^2\varphi}} -2\sqrt{1-k^2\sin^2\varphi}\,d\varphi\right),$$

or, with the usual notation,

$$dx\sqrt{L}=\frac{d\varphi}{\triangle\varphi}-2\triangle\varphi d\varphi \qquad (15)$$

Integrating, and determining the constant by the condition that $y=o$ when $x=o$, gives as the equation of the elastic curve

$$x\sqrt{L}=F(k,\varphi)-2E(k,\varphi)-F_1+2E_1 \qquad (16)$$

where $F(k,\varphi)$ and $E(k,\varphi)$ represent the elliptic integrals of the first and second kinds respectively, viz.:

$$\int_o^\phi\frac{d\varphi}{\triangle\varphi} \text{ and } \int_o^\phi\triangle\varphi d\varphi;$$

and $F_1$ and $E_1$ the complete integrals,

$$\int_o^{\frac{\pi}{2}}\frac{d\varphi}{\triangle\varphi} \text{ and } \int_o^{\frac{\pi}{2}}\triangle\varphi d\varphi.$$

If (15) be integrated between the limits $o$ and $\frac{l}{2}$ for $x$, and the corresponding limits $\frac{\pi}{2}$ and $o$ for $\varphi$, there results the equation

$$\frac{l}{2}\sqrt{L}=2E_1-F. \qquad (17)$$

$E_1$ and $F_1$ are functions of $k$, and therefore of $y_1$. Equation (17) shows, therefore, that $\frac{P}{A}$ is not independent of $y_1$, as indicated by (9), but that the load the column will support depends upon the amount of flexure. If $y_1=o$, $k=o$, and

therefore $E_1=\frac{\pi}{2}$, $F_1=\frac{\pi}{2}$, and (17) becomes

$$l\sqrt{L}=\pi,$$

which is identical with (9). Hence equation (9) gives the resistance of the column just before bending takes place. If $y_1>0$, $E_1<\frac{\pi}{2}$ and $F_1>\frac{\pi}{2}$, hence (17) shows that

$$l\sqrt{L}<\pi$$

and therefore

$$\frac{P}{A}<\frac{E}{1+\frac{1}{\pi^2}\cdot\frac{l^2}{r^2}}$$

Hence the resistance of the column is decreased by bending. It may be concluded, therefore, that equation (9), when the values of $\frac{P}{A}$ derived from it are below the elastic limit, gives the true expression for the greatest resistance of round-ended columns.

For the case of fixed ends, (2) becomes

$$\frac{\frac{d^2y}{dx^2}}{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{\frac{3}{2}}}=-L(y-y') \qquad (18)$$

$y'$ being a constant. Putting $y-y'=z$, (18) becomes

$$\frac{\frac{d^2z}{dx^2}}{\left\{1+\left(\frac{dz}{dx}\right)^2\right\}^{\frac{3}{2}}}=-Lz$$

Integrating, and applying the conditions that $\frac{dz}{dx}=o$ when $y=o$ and also when $y=y_1$, we find $y'=\frac{y_1}{2}$ and

$$\frac{2}{\left\{1+\left(\frac{dz}{dx}\right)^2\right\}^{\frac{1}{2}}}=2-L\left(\frac{y_1^2}{4}-z^2\right),$$

or

$$dx=\frac{\left\{2-L\left(\frac{y_1^2}{4}-z^2\right)\right\}dz}{\sqrt{4L\left(\frac{y_1^2}{4}-z^2\right)-L^2\left(\frac{y_1^2}{4}-z^2\right)^2}}$$

Putting $\frac{2z}{y_1}=\cos\varphi$, $k^2=\frac{Ly_1^2}{16}$, the last equation becomes

$$dx\sqrt{L}=\frac{d\varphi}{\triangle\varphi}-2\triangle\varphi d\varphi, \qquad (19)$$

which is identical in *form* with (15). Integrating between the limits $o$ and $\frac{l}{2}$ for $x$ and the corresponding limits $\pi$ and $o$ for $\varphi$, gives

$$\frac{l}{2}\sqrt{L}=2\int_o^\pi\triangle\varphi d\varphi-\int_o^\pi\frac{d\varphi}{\triangle\varphi},$$

or

$$\frac{l}{2}\sqrt{L}=2[2E_1-F_1]. \qquad (20)$$

Reasoning as before, it is seen that when $y_1=o$,

$$l\sqrt{L}=2\pi,$$

which is identical with (10). When $y_1>0$, we have $l\sqrt{L}<2\pi$,

and therefore

$$\frac{P}{A}<\frac{E}{1+\frac{1}{4\pi^2}\cdot\frac{l^2}{r^2}}$$

Hence equation (10) gives the greatest resistance of fixed-ended columns, when the values of $\frac{P}{A}$ derived from it are below the elastic limit.

In determining, from equations (11) and (12), the least values of $\frac{l}{r}$ for which formulæ (9) and (10) are applicable, Q should be taken somewhat smaller than the number usually given for the elastic limit. For, in deducing (2) it was implicitly assumed that

$$\frac{\text{unit stress}}{\text{unit strain}}=\text{constant};$$

and the point at which this ceases to be practically true is probably somewhat below the elastic limit as usually determined. In the case of wrought iron, the usual values of E and Q give about $\frac{E}{Q}=1{,}000$. This would give for the limiting values of $\frac{l}{r}$ very nearly $\frac{l}{r}=100$ for

round-ended columns, and $\frac{l}{r}=200$ for fixed-ended columns. If Q be taken smaller, these values will be increased; and, in fact, experiment indicates that they are somewhat too small.

A rational formula for the resistance of columns of lengths below the above-mentioned limits, would have to be deduced from the properties of the material when stressed beyond the elastic limit. A satisfactory treatment of this problem would be difficult, if not impossible. But since a column, if subjected to a load that stressed the material beyond the elastic limit, would in time probably rupture, this limit would seem to be the proper guide in the designing of columns of lengths below the limits above specified. Especially does this seem the rational method in the case of a material, like wrought iron, of which the elastic limit can be readily and accurately determined.

In the case of a column with one end round, the other fixed, equation (2) takes a form the accurate treatment of which is less easy. But as the usual treatment of this case is not wholly satisfactory, it may be well to consider it, using the approximate value $\frac{d^2y}{dx^2}$ for $\frac{1}{\rho}$.

If one end is fixed, a constraining couple is applied to it. If the other end is free, no equilibrating couple can act there. Neither can equilibrium be produced by longitudinal forces acting along the axis of the column. There must, therefore, be brought into play transverse forces acting at the ends of the column. Let P be the transverse force at the free end. Then

$$M=Px-Py, \text{ and (2) becomes}$$

$$\frac{1}{\rho}=Lx-Ly, \text{ or approximately,}$$

$$\frac{d^2y}{dx^2}=L'x-Ly \qquad (21)$$

If (1) is used instead of (2), it takes the same form, with different values of L' and L. To solve (21), assume

$$L'x-Ly=\alpha\sin px+\beta\cos px.$$

This is found to be a solution if $p=\sqrt{L}$. We have then

$$L'x-Ly=\alpha\sin x\sqrt{L}+\beta\cos x\sqrt{L},$$

$$L'-L\frac{dy}{dx}=\sqrt{L}(\alpha\cos x\sqrt{L}-\beta\sin x\sqrt{L}),$$

$$-L\frac{d^2y}{dx^2}=-L(\alpha\sin x\sqrt{L}+\beta\cos x\sqrt{L}).$$

Here L', $\alpha$ and $\beta$ are unknown constants. Applying the conditions

$$y=0 \text{ when } x=0,$$

$$y=0 \text{ when } x=l,$$

$$\frac{dy}{dx}=0 \text{ when } x=l,$$

we have

$$\beta=0,$$

$$L'l=\alpha\sin l\sqrt{L},$$

$$L'=\alpha\sqrt{L}\cos l\sqrt{L}.$$

The last two equations give

$$\tan l\sqrt{L}=l\sqrt{L} \qquad (22)$$

Equation (22) may be satisfied by an infinite number of values of $l\sqrt{L}$. The smallest finite value is

$$l\sqrt{L}=1.43\pi \qquad (23)$$

very nearly, and this may easily be shown to correspond to the case in which the elastic curve does not cross the axis of x between the ends of the column,—the only case of practical importance. Equation (23) gives

$$\frac{P}{A}=\frac{E}{\frac{l}{r}\left(\frac{r}{\rho}\right)^2+2.05\pi^2\left(\frac{r}{\rho}\right)^2} \qquad (24)$$

or

$$\frac{P}{A}=\frac{E}{\frac{l}{r}\left(\frac{r}{\rho}\right)^2+2.05\pi^2\left(\frac{r}{\rho}\right)^2} \qquad (25)$$

according as equation (2) or equation (1) has been used.

The usual treatment of this problem leads to the formula

$$\frac{P}{A}=\frac{E}{\frac{l}{r}\left(\frac{r}{\rho}\right)^2+2.25\pi^2\left(\frac{r}{\rho}\right)^2}$$

and the same reasoning, using equation (2), would give

$$\frac{P}{A}=\frac{E}{\frac{l}{r}\left(\frac{r}{\rho}\right)^2+2.25\pi^2\left(\frac{r}{\rho}\right)^2}$$

These give values of $\frac{P}{A}$ about 10 per cent. greater than those found from formulæ (24) and (25).

# COMPRESSED GUN COTTON FOR MILITARY USE, WITH SPECIAL REFERENCE TO GUN COTTON SHELLS.

By MAX V. FORSTER, Premier Lieutenant a. D., Technical Superintendent of the Gun Cotton Factory of Wolff & Co., Walsrode. Berlin, 1886.

Translated, with the Author's permission, by JOHN P. WISSER, First Lieutenant 1st Artillery, U. S. Army.

## I.

### PREFACE.

In continuation of our previous experiments,* we have made further investigations with compressed gun cotton, with reference to its explosive force, using larger quantities of the explosive and confining it in a closed space.

We have endeavored to establish relations in the experiments similar to those existing in military practice. With reference to the application of compressed gun cotton for military purposes, we have considered the value of the use of paraffin in connection therewith, as well as the coating of the gun cotton by dipping it in a solvent; and finally we have instituted extensive experiments on the explosion and firing of gun cotton shells, with special reference to granulated gun cotton for charging the shells.

In the recent work of Lieutenant-General Brialmont, *La fortification du temps présent, Bruxelles, 1885*, attention is called to the importance and effect of gun cotton shells, and a shell filled with gun cotton in the form of disks is described in full, so that we feel convinced that the record of our experiments in this direction will be of interest.

Our experiments with shells were carried on for several years entirely at our own suggestion and at our own expense, with the exception of the experiments of firing and exploding six caliber steel shells, which were conducted in our presence by a foreign artillery.

A part of the results of our experiments was made public by the following patents taken out in Germany, in conjunction with W. F. Wolff:

1. No. 22,418. Method of exploding compressed gun cotton under water. September 1, 1882.

2. No. 24,674. Projectile containing a charge of compressed gun cotton. January 14, 1883.

A shell, the head of which may be unscrewed and the shell filled with gun cotton in the form of disks, and containing a primer, independent of the fuse, placed near the bottom of the shell.

3. No. 26,014. Method of coating pieces of compressed gun cotton, compressed nitrated wood and other forms of cellulose, partially or entirely, by treatment with a solvent thereof. March 9, 1883.

4. No. 33,867. Method of filling hollow projectiles with compressed explosives in a granulated form. May 2, 1885.

Our experiments, so far as the objects acted on are concerned, could be carried on only to the extent possible in a manufactory, but the results, we hope, will furnish data for all sorts of objects.

We are able, however, to furnish several examples of experiments with explosives on sunken ships and wrecks, carried on by us under the direction of the imperial admiralty, the imperial pilot command of Wilhelmshaven, and various other commands, as well as of private persons, which illustrate the effect of compressed gun cotton in submarine explosions in its larger relations.

We have used exclusively gun cotton prepared in the powder and gun cotton works of Wolff & Co., Walsrode. This gun cotton is used in all arms of the German Army, and has been tested by the German Navy, accepted, and a considerable quantity stored; it is supplied to many European and foreign armies and navies, and must therefore be regarded as fulfilling all the requirements of the best compressed gun cotton, and the results obtained must be regarded as applying to all good gun cotton. The gun cotton, unless otherwise specified, has a specific gravity of 1.1, and contains, on an average, 12.6 per cent. nitrogen,

* Experiments with Compressed Gun Cotton. Van Nostrand's Engineering Magazine, August, 1884.

calculated on the weight of the absolutely dry gun cotton, just as it is, that is, including chalk and foreign ingredients.

It is well known that wet gun cotton is detonated by means of a corresponding weight of dry gun cotton, and we have done this even when it is not particularly stated.

The dry gun cotton we have detonated by means of a primer containing 1 grm. mercuric fulminate from the Linden Primer Factory, in Egestorf, Linden, near Hanover. These primers act very satisfactorily, even after having been five years in store.

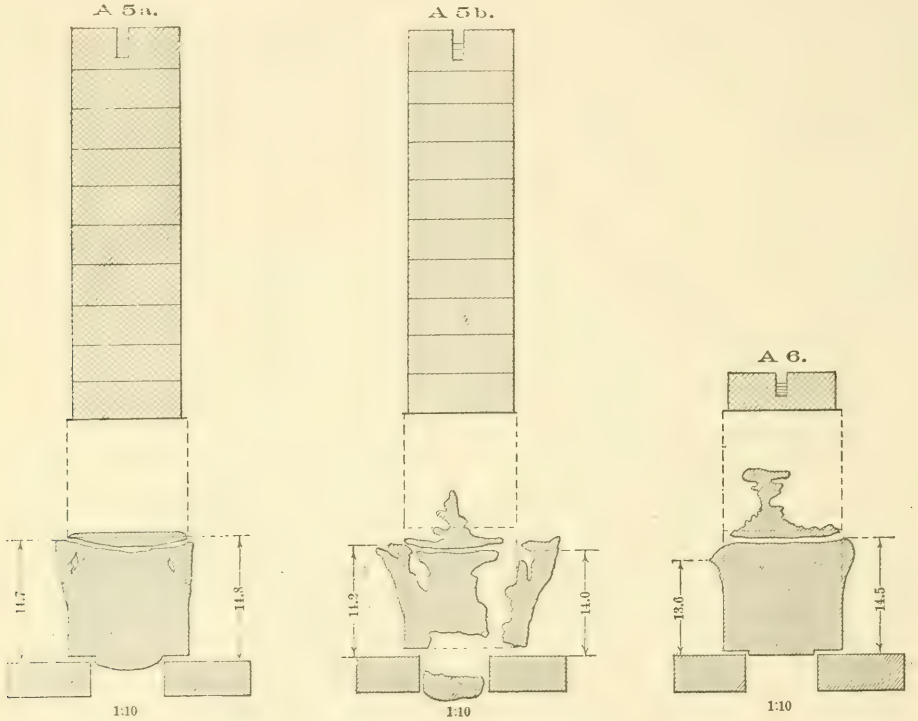
*Experiment No. 5a.*—6,500 grm. dry gun cotton disks, 14 cm. in diameter, and, in toto, 43 cm. high.

*Experiment No. 5b.*—6,500 grm. wet gun cotton disks, same weight dry plus 25 per cent. water and of the same dimensions.

Base consisting of two superposed blocks of rolled lead, 15 c.c. in volume. The lower block stood on a perforated iron plate.

The dry gun cotton destroyed the upper, the wet also the lower block.

*Experiment No.* 6.—A gun cotton disk, 14 cm. in diameter, 6 cm. in height,




EXPERIMENTS RELATIVE TO THE FORCE EXERTED IN THE EXPLOSION OF COMPRESSED GUN COTTON.

*A. Dry and Wet Gun Cotton, not Confined, Placed on Lead Cylinders and Detonated.*

*Experiments Nos.* 1–4.—360 grm. gun cotton, placed on lead cylinders 46 mm. in diameter and 100 mm. in height, destroyed the latter—the dry gun cotton to one-half its depth, the wet gun cotton almost completely.

weighing 920 grm., dry, containing a primer, and placed on blocks similar to those in *5a* and *5b*, destroyed them to at least the same extent, so that a charge of 900 grm. acted quite as effectively, if not more so, on the support directly underneath, as a charge of 6,500 grm., the surfaces of contact in the two cases being equal. In this experiment the result may perhaps be attributed to the effect exerted by the primer on the development of the explosive force of the gun cotton.

In the succeeding experiments the weight of the gun cotton employed was so far reduced that the object against which the force was exerted, the resistance of which was considerable, was not entirely destroyed. The charges, which were still considerable, acted in such wise that funnels with raised rims were formed in the blocks, while the upper surface of the blocks surrounding the funnels remained intact. To determine the effect, the rim was cut through vertically down to the unaffected upper surface of the block, and thus the level of the upper surface was marked on the interior of the funnel. The volume of lead displaced from the core of the block was then measured by filling the funnel to the mark with water from a glass tube graduated in cubic centimeters.

The greater the number of cubic centimeters of lead displaced, the greater the explosive force of the gun cotton.

The blocks of lead were so large (12 cm. cube), that a considerable weight of gun cotton could be employed.

GUN COTTON CARTRIDGES.—38 *mm. in diameter*, 50 *mm. high*, 63 *grm. in weight.*

*Experiment No.* 7.—1 dry cartridge displaced..... 27 c.c.

*Experiment No.* 8.—1 wet cartridge, detonated by a superposed dry cartridge like No. 7, displaced..... 36 c.c.

*Experiment No.* 9.—8 dry cartridges, like No. 7, placed one above the other, displaced..... 33.5 c.c.

GUN COTTON CARTRIDGES.—60 *mm. in diameter*, 50 *mm.* high, *of various weights.*

*Experiment No.* 10.—1 dry cartridge, specific gravity 1.1, 153 grm. in weight, displaced..... 60 c.c.

*Experiment No.* 11.—1 dry cartridge of the same dimensions, specific gravity 1.28, 178 grm. in weight, displaced..... 90 c.c.

*Experiment No.* 12.—The experiment was repeated. Weight of cartridge, 175 grm., displaced..... 90 c.c.

*Experiment No.* 13.—1 cartridge, as in 11 and 12, but with 18 per cent. water, containing an excavation sufficiently large to receive a dry priming cartridge weighing 32 grm., of specific gravity 1.1; the dry weight of the total amount of gun cotton employed was therefore the same as in 11 and 12, the volume as in 10, 11 and 12. Lead displaced.. 148 c.c.

Or, $2\frac{1}{2}$ times as much as in 10, and $1\frac{3}{5}$ times as much as in 11 and 12.

*Experiment No.* 14.—As in No. 13, but the priming cartridge weighed only 12.5 grm., specific gravity 1.1, so that 12.5 grm. gun cotton were wanting; the lower result is not, however, attributable to this. Lead displaced..... 110 c.c.

*Experiment No.* 15.—Cartridge as in 13 and 14, the priming cartridge, however, composed of 8 pieces, placed one on the other, 38 mm. in diameter, and weighing 63 grm. each. Primer placed in the uppermost cartridge. Lead displaced... 143 c.c.

Although, as previously shown, the action of the last cartridge in long charges, here the eighth, is less, in comparison, than that of the first, nevertheless the eighth cartridge served effectually as a priming cartridge, and forced the gun cotton detonated by it to a full development of its explosive force.

*Experiment No.* 16.—3 cartridges, applied as before, 60 mm. in diameter, 50 mm. high specific gravity 1.1, total weight 410 grm., all three dry, displaced..... 120 c.c.

*Experiment No.* 17.—3 similar cartridges, but of specific gravity 1.3, weight 488 grm., dry, displaced... 200 c.c.

*Results.*—Gun cotton with a specific gravity considerably above 1.1 gives higher power, and the latter increases more rapidly than the absolute weight of the gun cotton used.

It is therefore, in general, advantageous to use gun cotton of the highest possible specific gravity (when the space available for the charge is limited), although the following experiments, conducted with shells, as well as those in which the charges are not in direct contact with the object, show that, under circumstances other than those thus far considered, the superiority of the gun-cotton of higher specific gravity is less noticeable.

*Effect of gun cotton against objects with which it is not in direct contact, but separated therefrom by an air space.*

In order to obtain data for the comparison of the following experiments, the preliminary test described under 1 was made.

1. A cylinder of gun cotton, 60 mm. in diameter, of specific gravity 1.2, 181 grm. in weight, was placed on a piece of wrought iron, 30 mm. thick and detonated.

The effect was as follows:

A trough-like depression was produced

in the iron, of the diameter of the piece of gun cotton, 8 mm. deep in the center. Besides, the effect on the lower surface of the iron was very much more marked, —the iron was nearly perforated.

2. A cylinder 60 mm. in diameter, of specific gravity 1.3, 181 grm. in weight, placed 34 mm. above a piece of iron similar to that in 1, hence, separated from it by an air space of 34 mm., made an impression 55 mm. in diameter and 3 to 4 mm. deep.

3. A cylinder 60 mm. in diameter, specific gravity 1.1, 156 grm. in weight, applied as in 2, made an impression 55 mm. in diameter, $1\frac{1}{2}$ to 2 mm. deep.

Moreover, the iron received a crack in 2 and 3, running in the direction of the fibers, which penetrated to the under side.

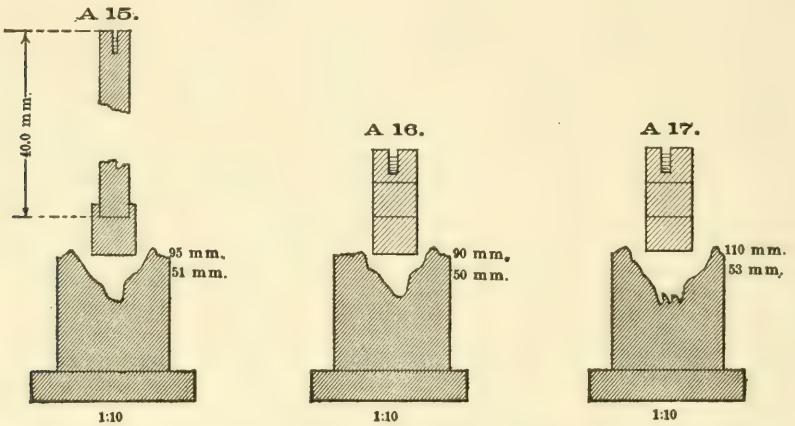
oak board 25 mm. thick. The detonation peeled the bark off the pine and split a piece lengthwise from the board.

7. Another charge was similarly arranged, but of 400 grm. weight, and at only 15 cm. distance from the tree. The latter was broken and a piece was split from the board as before.

*Results.*—In case of an open space between the charge and the object to be destroyed, the effect is thereby greatly diminished; and in case the open space is considerable, no great difference in action is observed between gun cotton of specific gravity 1.3 and that of specific gravity 1.1.

*B. Experiments with Gun Cotton enclosed in Cast Iron Shells.*

The gun cotton was in the form of disks, 139 mm. in diameter and 50 mm. high, with a specific gravity of 1.1. The shells were provided with a cavity corresponding to the diameter of the disks, the side walls were 32 mm. thick, the bottom 60 mm. and the head 120 mm.




The shells were placed upright on two superposed lead blocks, each 15 c.c. in volume, such as were used in former experiments, and which were, as in the previous experiments, set on an iron plate provided with a central opening. The upper block was always more or less disturbed. The effect could be more accurately measured by the depression made in the lower block, and by the amount of lead which was forced from the bottom of the lower block into the opening of the iron plate below.

The effect, considered as a whole, diminished in such a way that the ratio of 1 to 2 was as that of 2 to 3, the diminution in effect being quite considerable.

4. A piece of gun cotton, as in 2, specific gravity 1.3, was placed at a distance of 100 mm. from the iron, and made only traces of impressions on it.

5. A piece of gun cotton, as in 3, specific gravity 1.1, also 100 mm. from the iron, made also only traces of impressions, but even less distinct than in 4. The difference between 4 and 5 is, however, not great.

6. A charge of 254 grm. gun cotton was hung to a pine 9 cm. in diameter, at a distance of 20 cm. from the trunk and 35 cm. above the ground. On the ground under the charge was placed an

*Experiment No.* 1.—The shell was filled with 5,200 grm. dry gun cotton, the primer was in the upper gun cotton disk, hence on the side farthest removed from the object.

*Experiment No.* 2.—The shell was filled with gun cotton, containing 20 per cent. water, but of the same weight dry as No. 1. The upper piece of gun cotton was dry, and served to detonate the wet portions.

*Experiment No.* 3.—The charge of the shell consisted of wet gun cotton, containing 20 per cent. water, reamed out about the long axis of the shell to a diameter of 50 mm. In the head was placed a piece of dry gun cotton for detonation.

By analogy of gun cotton charges not confined, it was presumed that a very energetic effect would be produced on the object by the open central canal.

*Experiment No.* 4.—The shell was filled with wet gun cotton, containing 20 per cent. water; the lowermost disk, weighing 930 grm., was dry, however, and contained the detonating primer.

As shown in the diagrams B. 1, 2, 3, 4, the effect in 3, with a hollow charge, was the weakest; next in order came No. 1, the dry, then No. 2, the wet, and the effect was greatest in No. 4, in which the piece of gun cotton detonated by the primer was almost in direct contact with the object on which it was to act.

It has often appeared from the experiments that gun cotton detonated by the mercuric fulminate primer is more energetic in its action than such as, instead of being detonated directly by the primer, is detonated by other gun cotton; in this phenomenon, the distance, to which the primer acts directly, plays an important part; as soon as this distance is passed, we assume that the gun cotton is no longer exploded by the primer, but by other gun cotton.

With a view to a closer examination of the effect of the primer on the energy of the explosion, the following experiment was made:

*Experiment No.* 5.—Four blocks of lead, each 15 c.c. in volume, such as were used in previous experiments, were bored through the center, the diameter of the opening being 23 mm., one block not quite through, however, but only half way. The four blocks were placed one above the other, and fastened lengthwise by iron rails; the block bored only half way through at the bottom.

The channel in the four blocks, 52.5 c.m. deep, was charged with a charge of gun cotton, composed of several cartridges, 22.5 mm. in diameter and 45 cm. in length, so that the lower cartridge reached the bottom; into the upper cartridge, which was bored out for this purpose, was placed a 1 grm. primer with fuse attached, and the upper block closed with a leaden stopper, bored out for the passage of the fuse.

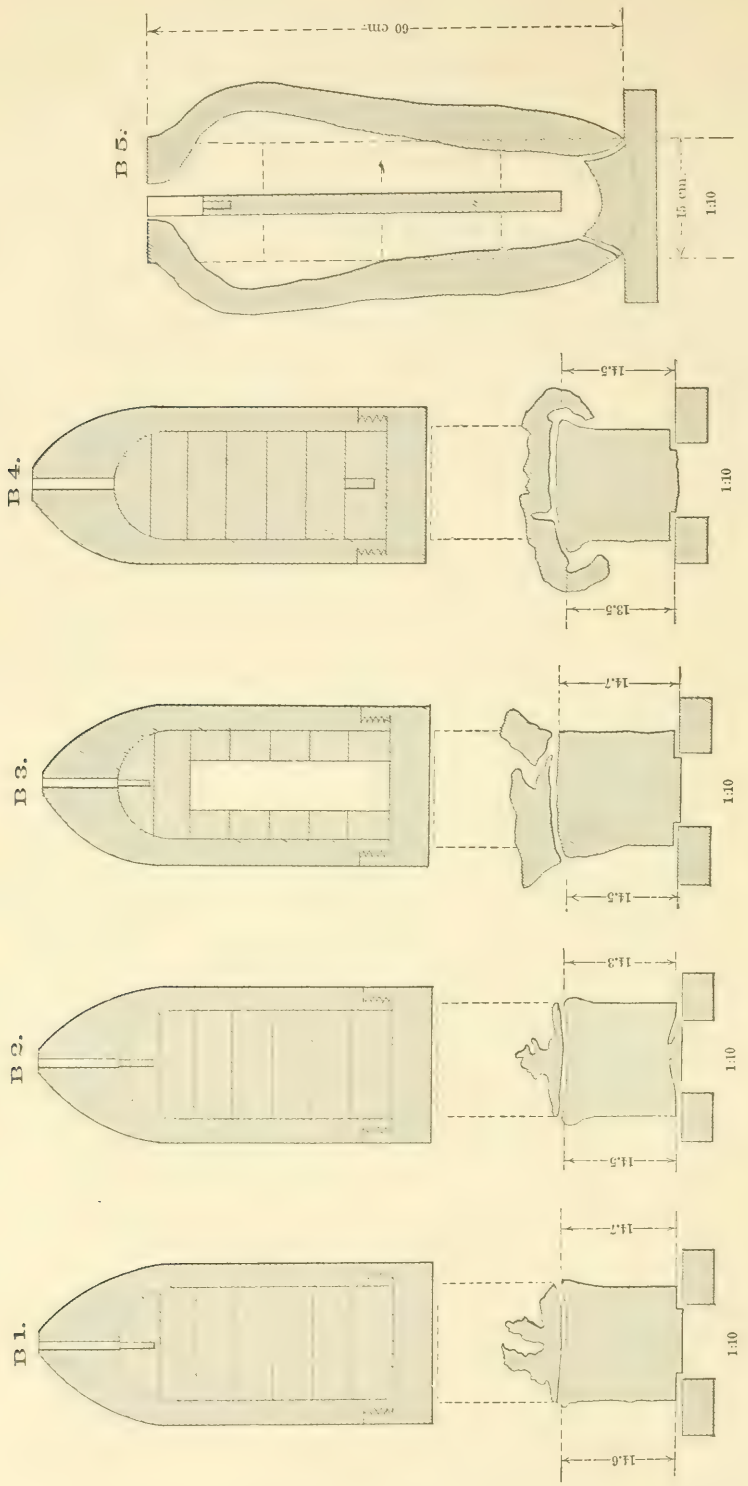
After the explosion of the cartridge the blocks were separated quite regularly into four parts, but when these parts were put together, a hollow space was seen to be formed therein by the explosion, which, in the upper quarter, where the primer had been placed, was 230 mm. in diameter, and in the lower quarter, or the one farthest removed from the primer, was 130 mm. in diameter. The spheres corresponding to these diameters are to each other as 6:1, so that it is apparent that the effect of the part detonated by the primer is six times as great as that of the lower part of the cartridge detonated by the progression of the explosion of the gun cotton.

We come to the conclusion, from these experiments, that it must be possible, by altering the physical condition of the gun cotton, or by a different method of detonation, to obtain a considerably increased effect.

The detonation of the primer develops the gases generated from the gun cotton in a very energetic form; the latter lose their force, however, against the elastic gun cotton which they meet, and cannot develop gases of the same energy as they themselves possess. Thus far it has been impossible for us to continue the experiments, using hollow lead blocks, nor to repeat them with gun cotton of specific gravity 1.3, and nitroglycerin, which is not elastic; nevertheless the experiments with charges applied externally, furnish important data.

Nor have we had opportunity to test the effect of shells filled with gun cotton, of specific gravity 1.3, against underlying objects, and, generally, objects of considerable resistance.

The difference in effect of wet and dry gun cotton is not very apparent in the ex-


B 5.
60 cm.
15 cm.
1:10
B 4.
14,5
13,5
1:10
B 3.
14,7
14,5
1:10
B 2.
14,3
14,5
1:10
B 1.
14,7
14,6
1:10

periments with shells, still, in all probability, it is considerable even in confined charges, but, in the experiments here given, its action was probably exhausted on the enclosing material itself. The bases of the shells were sufficiently thick for this to take place, 6 cm. This explanation could not be verified, because cast iron is a material which does not offer sufficient resistance to bring out the various differences in effect.

That an enclosing material, offering the same resistance in all directions, should affect the development of the energy of the compressed gun cotton, is very improbable.

If a piece of compressed gun cotton be placed on a piece of armor plate, or a piece of wrought iron of sufficient resistance, and detonated, its form will be accurately reproduced on the underlying object, and the action extends beyond this limit only so far as the parts of the iron plate, affected directly, tear along with them the parts lying adjacent. The gases produced by the detonation occupied, therefore, in the first instant, and indeed during their entire action, exactly the same form as, and no more space than, the piece of gun cotton previously occupied. How instantaneous the action is is shown by the following experiment:

If a coin be placed between a gun cotton cartridge and a wrought-iron plate, the figures and letters in relief on the coin will appear in the iron as depressions after the explosion; if, instead of the coin, a green leaf be inserted, the entire skeleton of the leaf will appear on the iron plate after the explosion. The more prominent, as well as the finer veins, protect the underlying iron, the more delicate parts of the leaf, lying between the veins, cannot afford the same protection; hence the depression under the latter is the greater.

### *C. Explosion of Shells on Rails.*

We exploded a number of shells on objects such as occur in actual practice, and used principally granulated gun cotton for the exposive charge.

15 cm. cast-iron shells, 2½ calibers long, containing a cavity 2 liters in capacity, were filled with granulated gun cotton. After being charged the spaces between the grains were filled with liquid paraffin, as will be described in detail further on. The dry as well as the wet grains were coated by means of acetic ether. The explosive charge consisted of:

*Experiment No.* 1.—Dry granulated gun cotton, 1,200 grm.

*Experiment No.* 2.—Wet grains, containing 25 per cent. water, and 250 grm. dry grains.

*Experiment No.* 3.—Wet grains, containing 25 per cent. water, and 150 grm. dry grains.

*Experiment No.* 4.—Wet grains, containing 25 per cent. water, and 100 grm. dry grains.

*Experiment No.* 5.—Grains entirely coated with paraffin and 300 grm. dry grains.

*Experiment No.* 6.—Grains entirely coated with paraffin, and 200 grm. dry grains without paraffin, gelatinized.

*Experiment No.* 7.—Wet grains, containing 25 per cent. water, and a dry priming cartridge 31 mm. in diameter, weighing 35 grm.

*Experiment No.* 8.—Dry grains, and a priming cartridge weighing 35 grm.

*Experiment No.* 9.—Grains entirely coated with paraffin, 150 grm. dry grains without paraffin, and a priming cartridge weighing 35 grm.

*Experiment No.* 10.—A half shell, cut lengthwise, filled with 1,000 grm. gun cotton in large prisms (volume of each, 140 c.c.).

*Experiment No.* 11.—Two prisms, each weighing 154 grm., as in 10, placed directly on the base of a rail.

*Experiment No.* 12.—One such prism, as in 11, placed on a rail.

*Explosions* 11 *and* 12 without the employment of a shell.

Each shell received a priming cartridge 16 mm. in diameter, 9 grm. in weight, for the reception of which a space was left in the filling; in the priming cartridge was placed the primer, containing 1 grm. fulminate.

The shells were placed on three iron rails, placed with the head down, as close together as possible, as shown in the diagram (C. 12).

All the shells exploded with perfect accuracy. The effect in all the shells was approximately the same, the rails were generally broken; when this did not take place completely, a similarly great energy exhibited itself in some other manner.

The effect in No. 10 was not greater

than in the preceding ones, showing that the grains are quite as effective as the gun cotton in disks.

In 11 the rail was cut smoothly in two twice, in 12 once; in comparison with the preceding explosions the effect was greater, showing that by confining the gun cotton its effect is not increased, on the contrary, the direct instantaneous action on the object is rather weakened, a phenomenon explained by the fact that the 20 mm. thick wall of the shell removes the charge that far from the object. We call attention to the fact that we speak of the *direct* action on the object; *total* effect, acting also at a distance, must be distinguished therefrom; in the latter such small distances as 20 mm. can have no effect. This distinction also accounts for the fact that, in all experiments in which the force can act only in one direction on an object in direct contact, only relatively correct results are obtained, and that our experiments, too, at times conducted by placing the gun cotton directly on the object, and at other times confining it, furnish no uniformly accurate results.

Moreover, if 9 cylinders of gun cotton produce no more effect on the object than one cylinder (see Experiments A. 5*a*, 5*b* and 6), it does not follow that in the first case more total energy, corresponding to the weight, was not developed. At all events, even considering exclusively the effect, wet gun cotton will have preference over dry, in case it is desired to destroy, by means of externally applied unconfined charges, such objects as walls, arches, iron plates, etc., where the surface of contact between the gun cotton and the object to be destroyed is the largest possible.

*Experiment No.* 13.—A shell, filled with grains entirely coated with paraffin. A priming cartridge, 31 mm. in diameter, 65 grm. in weight, placed in a space left vacant for it in the filling, failed to detonate the filling of the shell. There was a partial combustion of the charge.

*Experiment No.* 14.—A shell, filled with grains entirely coated with paraffin, and containing a priming cartridge 31 mm. in diameter, but weighing 100 grm., detonated perfectly.

In case grains composing the filling of the shell are not bound together by means of melted paraffin, a very much heavier, and therefore larger, priming cartridge is necessary for detonation than if this is the case.

*Experiment No.* 15.—A 21 c.m. cast-iron shell was filled with 4,200 grm. dry granulated gun cotton, and placed on a support formed of a double row of rails. Five iron rails were placed side by side on two wooden skids, four rails were placed between the first named rails. The skids were 1 meter apart, the rails therefore had a bearing of 1 m.

The shell was covered with earth to a depth of $\frac{1}{2}$ m. The action was very considerable; all the rails were broken, most of them at several points, and in addition a depression was formed in the ground $\frac{1}{2}$ m. deep. A bomb-proof covering can, therefore, no longer be made in this way.

### *D. Action of Gun Cotton and Gun Cotton Shells in Earth.*

*Experiment No.* 16.—A 15 c.m. shell, filled as above with granulated gun cotton, buried 1 m. deep in the earth, produces in light soil as well as in somewhat heavy soil (sandy clay) a cone:

60 cm. deep and 2 m. in diameter.

*Experiment No.* 17.—A 15 cm. shell, filled with 2,100 grm. ordinary gunpowder, produces a cone:
50 cm. deep, 2 m. long, and $1\frac{1}{2}$ m. broad.

*Experiment No.* 18.—A 15 cm. steel shell, 6 calibers long, filled with 8.9 kg. granulated gun cotton, wet, containing 25 per cent. water, 1 kg. dry grains, and a priming cartridge weighing 35 grm., so buried that the head was 1 m. under the surface, the base $\frac{1}{4}$ m., made a funnel:

1.3 m. deep and 4 m. in diameter.

(See diagrams).

### *E. Comparative Experiments with Granulated Gun Cotton and Gun Cotton Disks.*

The earth in which the explosions took place was light, clayey, sandy soil.

*Experiment No.* 19.—A tin canister, 3 calibers long, $7\frac{1}{2}$ liters in capacity, filled with:

6300 grm. wet granulated gun cotton, } 8 mm.
300 " dry " " " } cube.
50 " priming cartridge,

5620 " = total dry weight,

was buried so that one end was 1.2 m.

under the surface, the other 0.9 m.; it formed a cone in the explosion,

1.10 m. deep, and 3.30 m. in diameter.

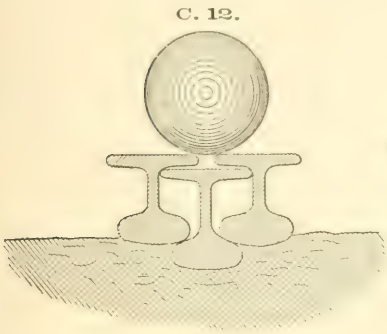
*Experiment No.* 20.—An explosive charge of the same form as in Experiment 19, but composed of disks of wet gun cotton, 8.3 kg. in dry weight, and furnished with a 50 grm. priming cartridge, was buried as in Experiment 19; it formed a cone in the explosion,

1.30 m. deep and 4.10 m. in diameter.

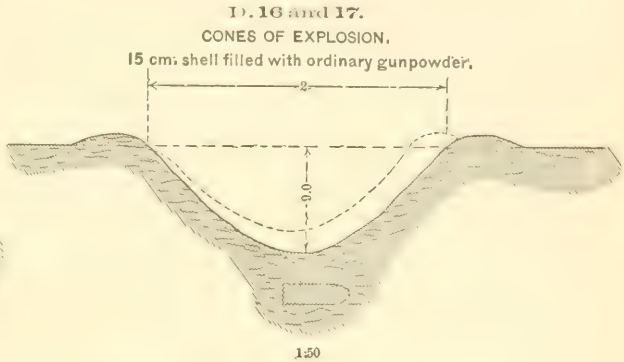
disks, 16.6 kg. in dry weight, provided with a priming cartridge weighing 50 grm., buried as in Experiment 21, formed a cone, in the explosion,

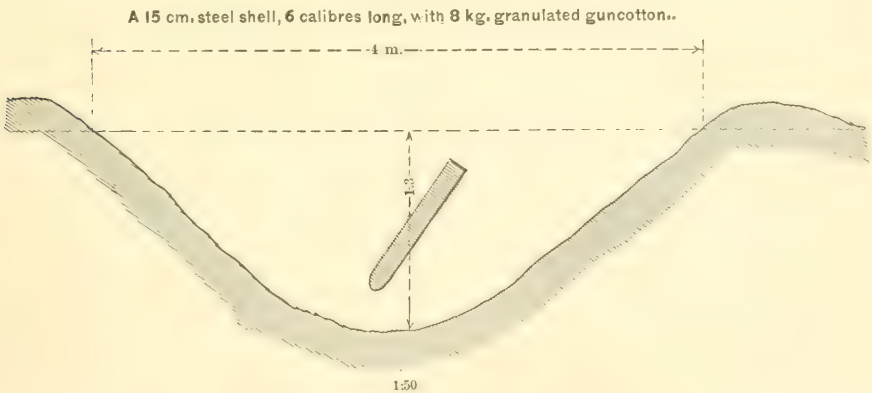
1.56 m. deep and 5.1 m. in diameter.

A piece of wrought iron 3 cm. thick, 10 cm. square in surface area, which, in the first two explosions lay close under one corner of the charge, in the second two explosions 15 cm. below the charge and parallel to its side wall, separated



C. 12.




*Experiment No.* 21.—A tin canister, 6 calibers long, 15 liters in capacity, filled with 11,150 grm. dry granulated gun cotton (8 mm. cube in volume, cubic weight 0.75) and a priming cartridge weighing 50 grm., was buried so that one end lay 1.2 m. deep, the other 0.6 m., and formed, in the explosion, a cone:

1.58 m. deep and 4.45 m. in diameter.

*Experiment No.* 22.—An explosive charge, composed of wet gun cotton

from it by earth, was, in Experiments Nos. 19, 21 and 22, compressed to an equal degree, but in No. 20, somewhat more than in the others. In Experiments 19 and 20, the iron lay, as remarked, immediately against the charge, and, under these circumstances, the disks were more energetic in their action than the grains.

*Experiment No.* 23.—A piece of iron rail, 0.5 m. long, 10 cm. broad in the base, 12 cm. high, was placed in a ditch

1.25 m. deep, resting on two pieces of fir, 10 square centimeters in cross-sections, so as to leave 25 cm. between bearings. Earth was thrown over the rail to a depth of 25 cm. above the head. A tin canister, like the one employed in Experiment No. 19, filled with 5,620 grm. dry grains and a 10 grm. priming cartridge, was placed on the earth with its axis perpendicular to that of the rail, and the ditch filled up to the surface. The canister was exploded—it cut the rail squarely across, dividing it into three parts, and besides, the base of the rail was driven 1 cm. deep into the wood. The pieces of wood were otherwise uninjured. The cone of explosion was:

1.10 m. deep, 3.10 m. in diameter.

The pieces of rail and the strips of wood were found at a depth of 1.50 m. under the surface.

*Experiment No.* 24.—A charge of wet gun cotton disks, of the same dimensions as the above-described tin canister, 8.3 kg. in dry weight, and provided with a 50 grm. priming cartridge, was applied as in Experiment No. 23 and exploded.

The iron rail was broken in almost the same manner as in No. 23, except that there were only two pieces, in each of which a piece was broken off from the head of the rail near the middle. The base of the rail did not penetrate into the wooden supports, but the latter were cut squarely and smoothly in two. They evidently offered less resistance than in Experiment No. 23. With the exception of this break the strips of wood sustained no injury.

The cone of explosion was:

1.5 m. deep and 3.5 m. in diameter,

hence, somewhat larger than in Experiment No. 23. The pieces of rail and the strips of wood were found buried at a depth of 1.65 m.

The charges Nos. 23 and 24 broke up the iron rails at a depth of 45 cm. below them, and threw out cones of explosion to a depth of 40 and 80 cm. respectively. The pieces of rail and the wooden supports were found pressed 90 cm. into the ground, and the sandy earth was ground to dust to the same depth.

This experiment shows that gun cotton in both forms acts not only when in direct contact, but with great force even at considerable distance.

From the comparative experiments it appears that in sum total the action of equal volumes of granulated gun cotton and gun cotton disks is the same; the excess in weight of over a third has no effect, especially when considerable weights are used, and the object to be destroyed is not in direct contact with the charge.

Whether, with other objects and under other circumstances, the excess of weight of the charge when disks are used over that of grains, will be made effective remains undetermined, but we believe from all the preceding experiments that we are forced to the conclusion that this can only take place to a slight extent.

We are furthermore of opinion that it is very doubtful whether, by the use of heavier and more sudden explosives, as, for instance, explosive gelatine, mixtures of the nitrates of benzole and aniline with nitric or hyponitric acid, in shells, a greater effect will be obtained.

In actual firing, the shells will rarely be in direct contact with the object which they are to destroy, but will more generally be some distance from it; *e. g.*, in case of arches and armor plates they will not lie in contact therewith along their entire length, but will either not be in direct contact at all or but very slightly, and at the smaller distances is just where the degree of suddenness of action of an explosive is most apparent.

In case of shells with thick cast-iron walls, the increased suddenness of action will probably have no other effect than to pulverize the walls to dust—an effect in many cases not at all desired.

It will be necessary, however, to test the various explosives under circumstances which resemble actual practice, in order to obtain comparative results of their power and action.

We will quote here a few examples from the above mentioned work of Lieutenant General Brialmont:

Ordinary 21 cm. steel shells, containing a charge of 14½ kg. of gunpowder, fired at an elevation of 45° from the Krupp 21 cm. forged mortar, penetrated from 2 to 2.60 m. into the sandy earth of the firing ground at Meppen, and threw out elliptical cones of explosion—

1.20 to 1.40 m. deep.
3.20 to 4.80 m. long.
3.20 to 4 00 m. broad.

Fired at 28° and 60° elevation, the action was less. A steel torpedo shell, 6 calibers long, containing a charge of 36 kg. of gunpowder, fired at 35° elevation, produced a cone of explosion,

2.40 m deep and 4.80 m. in diameter,

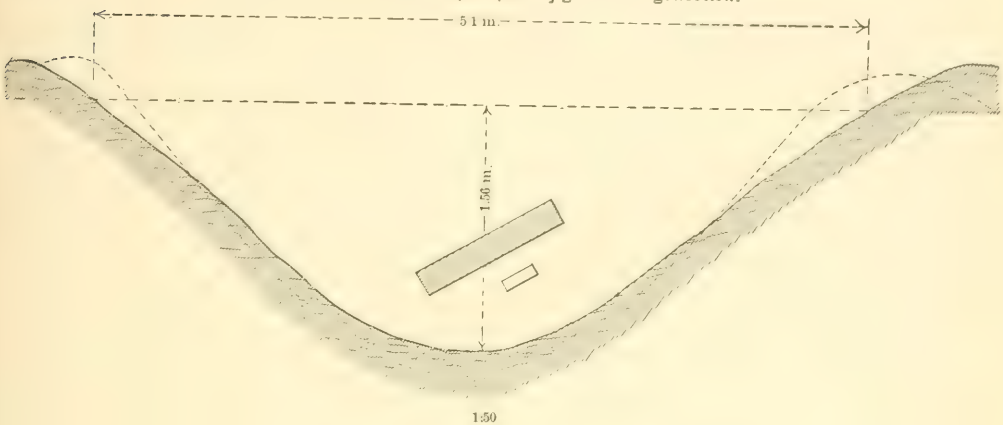
corresponding to a mean displacement of 15 cubic meters of earth.

Arches, constructed of the best béton, 1.45 m. thick, require the following thicknesses of sandy earth to protect them against various projectiles fired from the 21 cm. mortar:

E. 21 and 22.

CONES OF EXPLOSION.

16 kg. guncotton in disks, equal quantity granulated guncotton.

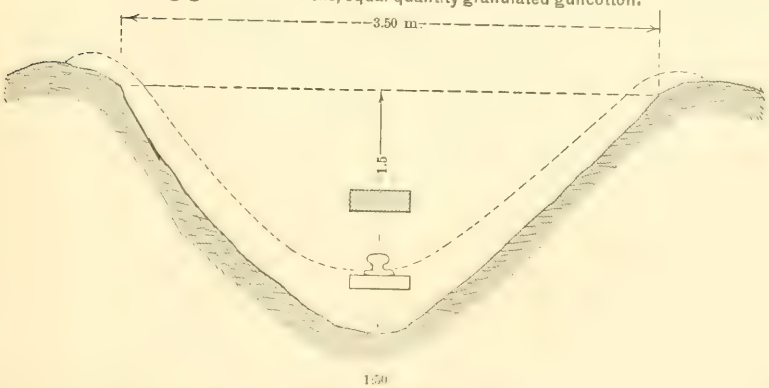



1:50

E. 23 and 24.

CONES OF EXPLOSION.

8 kg. guncotton in disks, equal quantity granulated guncotton.




1:50

1.00 to 2.20 m. deep,
3.20 to 5.00 m. long,
2.60 to 5.00 m. broad,

corresponding to a mean displacement of earth of 7 cubic meters.

The 21 cm. steel gun cotton shells penerate 4 m. deep, lying nearly horizontal, and throw out cones of explosion,

| | |
|---|---|
| Ordinary shells, | : 2.50 m. |
| Steel shells, charge 14½ kg. gunpowder | : 3 to 3.50 m. |
| Torpedo shell filled with gun cotton | : 5 m. |

But this thickness of earth covering of 5 m. cannot be attained in practice, as the fortification works will have to be too high and too costly. It is, therefore, pro-

posed to omit the earth covering entirely, and to replace it by a layer of granite or porphyry 0.80 m. in thickness, or by a bed of Portland cement 1 m. to 1.20 m. in thickness.

The experiments in Silberberg in 1869 showed, however, that even this covering will not suffice against the projectiles of the forged mortar charged simply with gunpowder, as these projectiles produced depressions of $\frac{1}{2}$ to $\frac{2}{3}$ m., so that a second shell striking the same point would penetrate the arch.

Lieutenant General Brialmont thinks, therefore, that it is not possible to propose anything definite on this subject as yet, but considers it preferable to construct the arches of the best béton, made 1 to 1.50 m. thick, and covered with at least 3 m. of earth. In case this is not sufficient, a part of the earth must be replaced by béton, or the earth covering must be increased, or an arch of sheet-iron may be inserted under the béton arch, which last is the simplest and cheapest method.

This, it is evident, approaches the armored turret.

We believe, however, that even this may be greatly damaged by means of large charges of gun cotton.

From all this it is evident that Lieutenant General Brialmont considers the power of the gun cotton shell, and its effect on the future construction of earthworks, as very great.

## Submarine Explosions with Compressed Gun Cotton.

*Explosion of the Iron Tug-boat Mathias Stinnes I., Sunk in the Rhine near the Railroad Bridge of Rheinhausen, below Duisburg.*

Conducted by the author and engineer Math. Rossenbeck.

The tug-boat was a strong iron vessel, dating from the earliest times in which such vessels were built, constructed especially solidly in all its parts.

She lay with the stern 200 m. from the railroad bridge, which stood on massive piers, and 100 m. out from the right bank of the Rhine, extending thence with its entire length down stream almost in the direction of the current. The stern at mean low water was about 2 m., the bow about 6 m. under water.

The vessel was to be cleared away to a certain depth of water, so that evidently the stern and center had to be removed. The current is so strong that a diver cannot descend without assistance.

A wooden Rhenish flat boat was therefore so arranged that an iron cylinder was laid square across its deck, containing on the end extending over the flat boat an iron ladder, which could be turned in its support. When the ladder hung free vertically it was held by a hand screw, but it could also be rested on the sunken vessel, on parts which had fallen off, or on the flatter parts of the river bottom, and rose in all cases 2 m. above the shaft. On the ladder a shild $\frac{2}{3}$ m. broad was fastened, which diverted the current from it. The ladder and shield could be raised and lowered by means of a hand-screw. By means of the ladder the diver could reach the vessel, and, protected by the shield, could work readily, mostly with the left arm.

A second flat-boat of the largest kind was provided with a solid deck and a crane, by means of which and an iron chain the parts separated by the explosions were raised.

Although large charges could not be used on account of the proximity of the railroad bridge, on which account heavy shocks had to be avoided, they would have been of no avail, but would more likely have been detrimental.

No charge, however large, even if 1,000 kg. of the most powerful explosive had been detonated at once, would have destroyed the vessel in such a way that the separated parts could be raised and removed. It would have left a conglomeration of parts of the vessel which, adhering firmly, would not have permitted the removal of the separate parts or the work of the divers.

The question was how to remove separate parts by charges not too great, and then to raise these parts by means of the crane on the flat boat. Wooden chests were therefore charged with 10 kg. compressed gun cotton, and used either separately or occasionally two at the same time.

The diver descended to the vessel, placed the charge in position, which often required hours on account of the strong current, ascended; the ladder was raised, the flat-boat went out to the middle of the

stream, and the explosion was effected by electricity.

The boat returned, the diver descended, fastened a chain to the loose parts of the vessel, an operation which again required several hours, on account of the exceedingly great difficulties, and an attempt was then made to raise the parts, which generally succeeded. Often the attempt failed, however, as the parts were still fast bound to the vessel, and the strong crane could not tear them away.

The iron planks, the ribs, the wheel, gradually the boiler, parts of the wheels, parts of the shaft and the machinery appeared in turn. The shaft was a cylinder of the best steel, 15 cm. thick, and was acted on by a double charge, hence by 20 kg. gun cotton, cutting it across in several places.

Great as was the action of the gun cotton, over 100 explosions, in which 1,200 kg. gun cotton were used, were found necessary to clear the water to the required depth. The greater part of the stern of the vessel was removed, the rest was forced into the sand of the stream by the force of the explosions; the bow of the vessel till beyond the wheel shaft was little disturbed; it lay, however, below the required depth of water.

It is shown again, in this example, that the annihilation of the vessel by means of charges of explosives is entirely out of the question; iron constructions are particularly difficult to remove, unless they are raised after the explosion or the force of the explosion pushes them into the ground.

To sink a floating vessel is quite another matter.

Charges of 20 kg. of gun cotton, applied externally to a suitable part of the vessel, and lying in direct contact, will burst through the sides of the vessel, but whether they will so disturb it as to make it sink is a question. So far as relates to its action at a distance, we have observed that in explosions in deep water, at a distance of 100 m. from a charge as much as 100 kg. in weight, only a light shock is given to floating material, such as vessels, and that, on the contrary, the shock produced by such an explosion is transmitted through the solid earth to considerable distances, 500 to 800 m., to other solid substances standing on the ground, such as buildings, for instance.

Wooden vessels are easily destroyed by explosion, because after the explosion they are removed by the water, by ebb and flood tide, or by other currents.

We have destroyed a large number of such sunken vessels on the coasts of the North Sea, and at the mouths of the Jade and Weser.

Charges of 100 kg. of gun cotton each, placed in long chests, were lowered to the wreck, or, when possible, fastened by divers to the side-walls of the wrecks, and exploded.

In the case of small vessels, two or three well-applied charges are sufficient; in the case of larger vessels, considerably more are required.

### Explosions at the Adlergrund.

In the Baltic Sea, between Bornholm and Rügen, lies the Adlergrund, a shoal formed by large rocks lying on the bottom of the sea. At the shallowest places the royal government, with a view to increasing the depth of water, had some of the rocks removed by vessels furnished with cranes.

Divers went down, fastened chains about the rocks, or attached clamps to them; the rocks were then raised. In order to break up the rocks and to render more easy the attachment of the lifting machinery, many charges of 10 kg. gun cotton each were placed on the bottom of the sea, to a depth of 4 to 6 m., and detonated. These explosions usually loosened from two to four blocks, each about 2 cubic meters in volume, and forced them completely out of their original position, so that they could be easily raised.

### *Rock-blasting in the Rhine, with a View to Deepening the Channel between Bingen and Coblenz.*

In many places rocks at the bottom of the Rhine form shoals which impede navigation, the best known and most dangerous of which is the "Bingerloch." From rafts and vessels a series of holes is bored in the rocky bottom, 1 to 2 m. deep, according to the amount of rock material to be removed; these are filled with gunpowder, tamped with sand, and the charge fired. After 10 or 20, or even more blasts, vessels provided with div-

ing-bells are run over the spot, the diving bell is lowered, and, by means of picks and bars, the rocks are broken loose, and are then raised through the diving bell to the surface and loaded into vessels held ready for the purpose.

We are of the opinion that if, in place of the gunpowder, *sudden* explosives are used, the work of removing the débris, which now involves the principal cost, will be greatly simplified and rendered cheaper. It is also necessary with gunpowder to deepen the bore-holes considerably below the point to which it is desired to remove the rock; fired with sudden explosives, the rock will be removed to the bottom of the boring, whereas by the use of gunpowder the lower third of the bore-hole remains intact. The sudden explosives are not used, because people still fear those who decry them, saying that a part of the explosive may remain unexploded, and when the diving-bell is lowered and the workmen proceed to loosen the rocks, may give rise to after-explosions, produced by the shocks in striking it, which may cause serious accidents.

This may be true of nitro-glycerine preparations, which are not rendered inexplosive by penetrating water, but in the case of gun cotton the cartridges, as the author has stated in his previous article, may be easily so arranged that, after a certain time, say 24 hours, they will become thoroughly wet and rendered inexplosive and perfectly safe, as well from the explosive priming cartridge, which may still remain, as from the shocks of the tools

Although advantages are gained by the use of compressed gun cotton in such work, we are nevertheless of the opinion that neither gun cotton nor any other sudden explosive can act so as to dispense with the boring of the bore holes.

Externally applied charges do not, even in case of considerable depth of water, which acts as a kind of tamping, act so strongly, but that the cost of explosives will be too great.

We can conceive of an advantageous method of carrying on the work with externally-applied charges, without the use of bore-holes, only in case large surfaces of rocks are to be removed to but slight depths, perhaps to 10 or 15 cm., in which case bore-holes would even act disadvantageously. The entire work of preparing the borings and the removal of the rocks is saved, and thus, in spite of the large amount of explosives employed, a relatively cheaper and more rapid work is obtained.

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## EXAMINATION OF A DEPOSIT FROM THE CHANNEL WAY OF THE U. S. S. RICHMOND.

By CHARLES E. MUNROE.

Written for VAN NOSTRAND'S MAGAZINE.

THE specimen examined was received from P. A. Eng. A. B. Canaga, U.S.N., with the following statement:

"The two Martin's vertical water tubular boilers of the Richmond are constructed of wrought iron with composition tubes. The entire area of the tubes in contact with the water is 5,208 square feet. The copper steam pipe leading to the two engines is 40 feet long and 1 foot in diameter. The copper exhaust pipes leading from the engines to the condenser are each 10 feet long and 15 inches in diameter. The surfaces in the cylinder and valve chest subject to friction of metal on metal are all cast iron; and the area of this rubbing surface for piston and slide valves is 116 square feet. The steam after being exhausted from the engines is condensed in a Newell's surface condenser, the condenser tubes being of composition and tinned. The area of the condensing surface is 3,970 square feet. The condensed steam falls to the bottom of the condenser and is removed through the 'channel way' by the air pump. The sediment of which you have a sample was taken from this 'channel way,' and about 12 bushels of this muck-like sediment were removed

at the time your sample was taken. This quantity had accumulated while the ship steamed about 11,000 miles. The principal lubricants used were olive and sperm oils, but some tallow was also used. The deposit, when removed, was black with some brownish spots. It was of a slimy consistency, with some little balls, which by the swash and agitation produced by the air pump, had become more solid in their consistency."

The substance as I received it had an earthy luster and was in the main of a dark brown color, but it was interspersed with portions having the ordinary color of iron rust. The greater portion was in the form of a powder, but there were some nodular masses, which, when broken open, displayed a black color and a metallic luster. No portion of the mass gave any evidence of metallic properties when hammered on an anvil, but it was highly magnetic, and it was found possible, when finely powdered, to roughly separate about 80 parts by the aid of a magnet. It was neutral to test paper. A portion soluble in water gave reactions for sodium, calcium, copper, sulphuric acid and chlorine. A portion soluble in ether showed fatty salts. A portion soluble in muriatic acid gave iron and copper. The residue showed graphite and silica. The quantitative results from the analysis of an air-dried sample may be summed up as follows:

| | | Per cent. |
|---|---|---|
| Loss over $H_2SO_4$ | (water) | 8.32 |
| Soluble in water | (NaCl, $CaSO_4$, &c.) | 8.36 |
| Soluble in ether | (Fatty substances | 9.62 |
| | $Fe_2O_3$ | .22 |
| | CuO | .07 |
| Soluble in HCl | $Fe_3O_4$ | 49.79 |
| | $Fe_2O_3$ | 11.21 |
| | CuO | 5.09 |
| Insoluble residue | (Graphite | 6.31 |
| | (Silica, &c | 1.85 |
| | | 100.84 |

## SEWER VENTILATION.

By GEORGE RICHARDSON STRACHAN, Assoc. M. Inst. C.E.

From Selected Papers of the Institution of Civil Engineers.

This paper contains a record of experiments at Chelsea on sewer-ventilation by down-draughts from cowls.

The experiments are not put forward as novel, but only as accurate observations under known conditions.

The sewer experimented on is in Jubilee Place, Chelsea. It is an egg-shaped brick sewer, 3 feet 9 inches by 2 feet 6 inches, with an inclination of 1 in 100. At the highest part it terminates in a dead-end, and at the other end joins a main sewer of the metropolitan system. At a point of 600 feet from the dead-end a head-wall is built in the sewer, and under it a dip trap to pass the sewage out. A safety-valve is fixed in the head-wall, to provide a means of discharge in the event of the dip-trap ceasing to act. The sewer is fairly well built, and receives the sewage of forty-four ordinary dwelling-houses, and the road-water from eight gulleys. The mouth of each of these drains is provided with a block-flap. The sewer was thus an elongated vessel, with a capacity of 4,300 cubic feet. The roadway above is practically level. Near the center of the length of the sewer a 15-inch pipe is inserted at springing-level, and is connected to a shaft against the side of a house. The shaft terminates at the parapet wall, and has on the top a lobster-back cowl, so arranged as to present its mouth to the wind. The mouth of the cowl is 15 inches in diameter, and the throat 9 inches in diameter. The height of the cowl above the road is 32 feet. At the dead-end a 12-inch pipe connects the sewer to a similar shaft against the side of a house opposite. This shaft terminates at a height of 22 feet above the level of the road, and is made to resemble a chimney-stack, surmounted with a 9 inch chimney-pot. At the lower end a 12-inch pipe connects the sewer to a shaft against the front of a house opposite, which terminates at the parapet with an open mouth, at a height of 31 feet above the level of the street.

The action of the system is simple. The wind, in passing the center shaft, turns the mouth of the cowl towards it,

and forces air down the shaft and through the fifteen-inch pipe into the sewer. It then divides into two currents, one passing down the sewer and out by the shaft at the lower end, and the other up the sewer and out by the shaft there.

Four air-meters were used to measure the velocities of the air entering and leaving the sewer. One was placed in the mouth of the downcast pipe in the center, where it joins the sewer; one in the mouth of the upcast pipe, where it joins the sewer at the lower end; one similarly at the high end, while the remaining one was used as a check-meter at each of these points in rotation. In every case the author entered the sewer and took the observations.

The following table shows the results. The experiments commenced on the 26th of February, and terminated on the 11th of April, both in 1885:

| Number of Experiment. | Duration of Experiment in Days. | Average Velocity of Wind in Miles per Hour. | Volume of Air entering Sewer in Cubic feet per Minute. | Number of Minutes taken to fill and empty Sewer with air. | Number of times per Day Sewer was filled with air. |
|---|---|---|---|---|---|
| 1 | 1 | 18.4 | 113 | 38 | 38 |
| 2 | 3 | 9 6 | 126 | 34 | 42 |
| 3 | 4 | 11.3 | 117 | 37 | 39 |
| 4 | 7 | 11.5 | 161 | 27 | 53 |
| 5 | 7 | 10 3 | 136 | 32 | 45 |
| 6 | 7 | 10 6 | 140 | 31 | 46 |
| 7 | 8 | 11.3 | 150 | 29 | 50 |
| 8 | 7 | 13.0 | 180 | 24 | 60 |
| 8 | 44 | 12.0 | 140 | 31.5 | 46.6 |

The fact that a sewer of this capacity had its gaseous contents changed every thirty-one and a half minutes during forty-four days, by the force of the wind on a self acting cowl, will probably be considered a satisfactory one. As a matter of fact, one-third of the theoretical volume of air which would have passed through the throat of the cowl at the velocity of the wind, if there had been no resistance or loss by friction, did actually pass through the sewer.

The influence of this volume of air on the interior of the sewer is beneficial. Instead of the slimy coating of bluish-white matter that adheres to the crown and sides of sewers ventilated by openings in the roadway, there is dryness for at least 100 feet on each side of the downcast shaft, and then a gradually-increasing dampness is found until the upcast shafts are reached. At these points the crown and sides of the sewer are damp, but the moisture is clean as compared with that of an ordinary sewer.

The air passing out of the upcast shafts has a very slight smell of sewer-gas. No complaints have been made as to it, either by the occupiers of the houses against which the shafts are placed, or by the neighbors, or by persons using the street.

The method of forming the shafts deserves mention. They are built against the walls of the houses, and are made of concrete. The pieces are moulded to a rectangular gutter-shape with a face 12 inches long and sides 6 inches long, so that when placed against the wall which forms the fourth side, a space 12 inches by 6 inches is enclosed. The sides are 1 inch thick. Near the end of each of the short sides a hole is moulded vertically through the piece, so that when the pieces are placed against the wall it exactly coincides with the eyehole of a holdfast driven into the wall. A stout wire is passed through these holes and eyes, and by this method the pieces are threaded to the building. The joints are made good with cement. As the outside of the shaft is marked to correspond to the courses of brickwork, it looks a part of the house, presenting the appearance of

a pier. Where necessary, mouldings are placed to further improve it.

t occurs to the author that the system might be usefully applied by fixing a cowl and shaft, of suitable sizes, at the rear of houses, connected with the house-drains. The air would pass through the house-drain into the sewer, and out of upcast shafts placed at suitable intervals. By this means the house-drains, as well as the sewer, would be ventilated This method would do away with the necessity of the deep siphons now fixed in house-drains to protect the house from sewer-gas, which the author has occasionally found, in small property, to become stopped.

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# WATER PURIFICATION—ITS BIOLOGICAL AND CHEMICAL BASIS.

By PERCY F. FRANKLAND, Ph.D., B.Sc., (Lond.), F.C.S., F.I.C., Associate of the Royal School of Mines.

Proceedings of the Institution of Civil Engineers.

## II.

DISCUSSION.

Sir Frederick Bramwell, President, said the paper dealt with a subject the importance of which was year by year more recognized, and which had received much attention resulting in a practical end. He wished to remind the members that during the last two or three sessions papers had been read on the same subject, and many gentlemen competent to speak upon it had given their views at considerable length, and those views had been fully set forth in the Minutes of Proceedings. While therefore hoping that there would be a thorough discussion upon the paper, he desired that, as far as possible, it should not be a mere repetition of what had already taken place and had been recorded.

Dr. Percy Frankland asked permission to show the exceedingly simple process that had been devised by Dr. Koch, for determining the number of micro-organisms in water or in any other liquid. He exhibited some of the nutritive material prepared by adding a certain quantity of gelatine to rich beef-tea. It was contained in a test-tube, plugged with cotton-wool, to prevent the ingress of any aerial organisms which would in a day or two cause the gelatine to become putrid and enter into decomposition. So plugged it remained limpid for an unlimited period of time. Before being used the gelatine was melted, which he would do rapidly over a spirit-flame. In practice it was melted at a definite temperature, 30° Centigrade. It had a melting point of about 26° Centigrade, so that it would stand the ordinary indoor temperature experienced in this country in summer. The water intended to be examined by the process was collected in a small bottle which also had been rendered perfectly free from any accidental micro-organisms by heating it in a tin box, care being taken at the time of collection to prevent the entrance of organisms from the hand or from other accidental sources. The gelatine, it would be seen, was now perfectly liquid. The stopper was next removed from the bottle, and a pipette, which had been also rendered free from organic life by heating, was introduced into the water. The cotton-wool was carefully removed, and a certain quantity of the water was introduced into the gelatine in the tube. The wool was then replaced, and the gelatine and water were mixed together. When they were thoroughly mixed they were poured upon a sterilized glass plate which rested upon another perfectly horizontal plate kept cold by means of a dish filled with iced-water placed beneath, and which caused the gelatine poured upon the upper plate to set in the course of a few seconds. The gelatine was poured carefully over the surface of the plate in a rectangular form, and was covered with a bell-jar until the film was solid. When set it was put upon a horizontal stand in

a dish with a glass cover over it to prevent any aerial organisms falling upon the surface of the gelatine. Into the dish was poured a little water to keep the interior in a moist state, otherwise the gelatine dried, and the organisms would not grow on the plate. In two or three days the organisms made their appearance as colonies. He would show them in a magnified form on the screen. These colonies were distinctly visible to the naked eye, and they could be readily seen and counted with the assistance of a microscope of low magnifying power. He would first show what the appearance of the plate was after it had been allowed to develop in the glass dish at a suitable temperature. Each of the large spaces shown on the screen was a colony originating from a single micro-organism introduced into the gelatine. There were different kinds of colonies, some consisting of the large spaces that were scattered about, while others were comparatively small specks, but still readily perceptible. The large colonies were those which caused liquefaction of the gelatine. The little specks on the field were colonies which did not liquefy the gelatine. The next specimen was from some water before filtration through coke, and the next was from the same water after filtration through coke. It would be seen that there were an immense number of organisms in the first specimen, and scarcely any in the second. Another plate would show the effect of agitation with coke, and another the same water after agitation and a certain subsidence. There were, as would be noticed in the first specimen, numerous liquefying organisms besides many of the colonies which did not liquefy; but in the second specimen comparatively few colonies were left. He would also exhibit a few plates with unfiltered river water collected at Hampton, containing a large number of organisms. The next examples were from the ordinary Thames water supply of the various companies in London, which for obvious reasons he would not specify. It would be seen that the number of organisms was enormously diminished, although a considerable number still remained in the field. Another specimen was from the unfiltered water abstracted by the East London Company at Chingford, and another example was filtered water from the Lee, where the diminution in the number of organisms was exceedingly striking. The next specimen represented the average filtered Thames water, which contained very few liquefying organisms, but still many colonies were distributed over the field. A specimen of the Kent Company's water, as would be seen, was remarkably free, only a few colonies remaining.

Mr. C. E. Conder, having given considerable time during the last twelve months to the practical study of the theme brought forward for discussion, wished to express his concurrence in the paper. Many persons might possibly have heard the author speak on the same subject at the Society of Arts two years ago; and they could not but be struck with the gigantic strides that had been made in the interval. He desired to confine himself within the lines laid down by their first President, Mr. Telford, and speak merely of practical investigation in that great field of inquiry. The paper by Mr. G. H. Ogston on the subject of the purification of water by iron, and another recently read by Mr. Winter Blyth, at the Royal Society, together with some discoveries of his own, brought the whole subject into harmony. With regard to the author's fifth conclusion, he hoped that in speaking of biological resurrection he would not lose sight of chemical resurrection. That water might be purified for a time, and then become impure, there could be no doubt. Even with the great purifier, permanganate of potash, he had found that within a week or ten days there was a resurrection of turbid matter in the water, and finally an abominable putrefaction. But the great source of secondary action which interfered with all efforts in the purification of sewage was lime. The Rivers Pollution Commission had spoken of it authoritatively as a clarifier, and not as a purifier; and the secondary action which took place from the use of it was well known. At Hertford, where the sewage was remarkably weak, and where a small dose of lime, under 4 grains to the gallon, was applied, the secondary action took place some miles down the river, at Ware; the water then being of a most offensive nature, as was reported by Major Flower in 1876. The same

secondary action had, he believed, been observed in almost every place where the effect of lime had been carefully watched, and most certainly where it had been mixed with iron. In the only instance of secondary action occurring in his experiments, it was due to the presence of lime and iron. At Bradford, Clifton, and Cheltenham, the same thing had occurred. In one case chloride of iron was used, and in another sulphate of iron. The secondary action was of so foul a nature that the Court of Chancery interfered by injunction, and the works were abandoned. In every case where the two substances—lime and iron—were applied together the same result had happened.

Sir Frederick Bramwell reminded Mr. Conder that the subject of the paper was the purification of water for potable purposes, and not the purification of sewage.

Mr. C. E. Conder said it was exceedingly difficult to draw a line. He did not wish to describe at length any process of his own, unless invited to do so by the Council; but he desired to draw attention to the samples of purified water on the table, which in two cases had been treated in the sewers themselves. There were seven points to be considered in the purification of water and sewage. The first was the destruction of odor and of gas, one of the most fatal causes of disease. The second point was the destruction of micro-organisms in the water, and there was distinct proof that iron was the only substance which absolutely destroyed those organisms. There was not a complete accordance between the experiments of Mr. Blyth and those of Mr. Ogston with sulphate of iron. That might be explained by the fact that Mr. Blyth had used an exceedingly strong solution.

Sir Frederick Bramwell again called Mr. Conder's attention to the fact that the subject under discussion was the purification of water for potable purposes, and not the purification of sewage. Although Mr. Conder had stated that it was often difficult in practice to discriminate between the two, yet in a discussion there was no such difficulty.

Mr. G Bischof thought that the grain of the materials, referred to in the paper as employed in filtration experiments, was too fine for practical purposes, and he believed that all waterworks engineers would bear him out in that opinion. He also considered that the rate of filtration with one or two exceptions was too slow to render the results practically applicable. With regard to the agitation experiments, he endorsed the author's conclusion that the process was unreliable, owing apparently to the numerous conditions which were necessary for its success. Considering the influence of storage on the increase of microphytes, to which he would presently refer, he contended that the samples in these experiments, which had been allowed to settle for half an hour, and for forty-eight hours, could not be compared. The redistribution of organisms referred to by the author was of interest, especially with reference to biological points, but it seemed to be almost in contradiction to the following statement: "During the period of storage, subsidence takes place, the water becoming poorer in suspended particles of all kinds." That would include micro organisms, and he therefore did not quite see how the two statements could be reconciled. Those acquainted with the subject were aware that when water was to be examined microscopically, it was allowed to settle for twenty-four hours, when an accumulation of microphytes would be found at the bottom. The reascension probably took place only when there were currents in the water. With respect to the filtration experiments on London waters, he might mention that he had in one instance succeeded in taking a sample directly the water had left the sand filter, and he there found a reduction of 89 per cent. There was one statement in the paper which he could not pass unchallenged: "Again, in these storage reservoirs a process of starvation may go on, for the organisms present in the impounded water find themselves imprisoned with a limited amount of sustenance, which they rapidly exhaust, and then perish in large numbers, falling to the bottom." He would ask the author to be good enough to reconcile that statement with the following experiment. He filled a number of glass tubes one inch in diameter, which had been sterilized, and drawn out at both ends to a fine point,

to about one-third their capacity with water containing twenty-seven liquefying, and two hundred and ninety total colonies per cubic centimeter. The two points were immediately sealed before the blow-pipe. He kept some of the tubes (in which the organisms were certainly on starvation diet) for forty-four days, and on the last day he found that the twenty-seven liquefying colonies had increased to eighty-three, and the two hundred and ninety total colonies to one thousand seven hundred. That was the result of the starvation. There was one other point to which he felt bound to direct attention. Some time ago he was as enthusiastic as the author himself about the gelatine test. He went to Berlin to see what was going on in Dr. Koch's laboratory, and had tried hundreds of tests, besides making a very large number of experiments, with the object of testing the method itself. He asked himself what was the meaning of those colonies, and why should they be the standard of purity of water? That plain question could be answered in two ways. The colonies might behave in the same way in which chemical poisons behaved. Chemical poisons were harmless in certain quantities, and became injurious or poisonous in others. So the colonies might be harmless in certain numbers, and become poisonous in others. He was convinced, however, that that was not so, at least within a very wide limit, say within a million colonies per cubic centimeter. He would not then give the proof of it, because he could combine that proof with another point to which he would afterwards refer. The only other way that he could see of connecting the colonies with purity was, if they indicated something else which was injurious to health. That something else in his opinion could only be pollution; he therefore asked were those colonies an indication of pollution? In order to answer that question, he might be permitted to refer to the conditions upon which the development of the colonies depended. Perhaps the most important of all those conditions was temperature, because at certain temperatures near the freezing point, the development was entirely stopped, and then it was gradually increased in a most marvelous way, until 30° or 40° Centigrade were reached. The next point was the time allowed for development, or, as it would be called in the case of water, storage. Many of the members were probably aware of the interesting calculations made by one of the foremost bacteriological authorities —Dr. Cohn, of Breslau—some years ago, that a single bacterium would be able to fill up the whole of the ocean with its progeny in less than three days, if only a sufficiency of food, and proper temperature, were given. That brought him to the third condition, food. The fourth condition was aeration, and the last, light. It was evident that of those conditions, temperature, storage, and light had no connection whatever with pollution. Aeration certainly had such a connection, but unfortunately it was of a reverse kind, because it was well known that when there was a deficiency of oxygen, the development of microphytes was checked. Therefore, as the deficiency of oxygen coincided generally with impurity of water, so the impurity of water would actually check, as far as aeration went, the development of microphytes. Thus the only condition remaining was food. This undoubtedly was always the result of pollution, but it should be borne in mind that even in distilled water—which certainly was not polluted, in the common sense of the word, and where there was but a scanty trace of food—enormous numbers of microphytes were sometimes developed. He would go one step further. He had taken a sample of New River water, which would have been called very good in quality by Dr. Koch, if it had contained even twice the number of colonies that he found, namely fifty-three. He had kept the water for six days in a sterilized flask, protected against aerial infection, and then found that instead of one liquefying colony he had six hundred and forty, and instead of the total fifty-three he had seven hundred and seventy thousand colonies per cubic centimeter. If that water could by any possibility be hurtful, it surely would have been known long since from experience, as water was frequently kept on board ship under much more unfavorable conditions and for a much longer period. That was the proof that he had promised, that even water containing such a number of colonies was not necessarily hurtful. He would also

ask this question, if in such water containing so few organisms, and generally so pure, such enormous numbers of microphytes could be developed, was it justifiable to say that no microphytes could be developed unless there were pollution? He hoped that he should not be misunderstood. He was fully convinced of the value of the method, but it should be applied with discrimination. Above all, no attempt should be made to compare totally different waters by the numbers of colonies found. Waters which had precisely the same history might well be compared, but that meant in reality identical waters, or one and the same water, which restricted the applicability of the test. Of course there were a great many laboratory experiments, for which the test was very useful. The author had said that it made a difference when there were different kinds of microphytes, but he could find no allusion whatever to different kinds. The numbers of total colonies only, and not even of the liquefying colonies, were given, and he presumed the author considered that the former were sufficient; otherwise he would have added an explanation to render them sufficient. His opinion, therefore, was that sufficient advance had not yet been made to draw definite conclusions from different kinds of microphytes. The last point to be considered was, whether the search for those specific microphytes, which were the cause of zymotic diseases, such as cholera and typhoid, could be of assistance in drawing conclusions from the test. If the author would be good enough to show him first the bacillus of cholera and of typhoid, he would search for them in samples of water. It was true that Dr. Koch was of opinion that the Comma Bacillus was the cause of cholera, but as long as bacteriologists and pathologists could not agree upon the point, he as a chemist could not be expected to pronounce an opinion upon it. He hoped, therefore, that the author would be good enough to explain thoroughly why he believed that those colonies had any necessary connection with wholesomeness.

Mr. Jabez Hogg remarked that the purification of water in its many-sidedness had been pretty freely thrashed out on former occasions. However, a very important change had taken place. It was now admitted by the analytical chemist that henceforth water purification must rest on a twofold basis—biological and chemical. In the earlier attempts at purification, water-engineers, and he thought he might say all classes of the community, were content if by filtration all visibly suspended matters were removed. If the water after passing through a filter bed had a bright, clear appearance, it was said to be a good and wholesome water. More recent investigations, however, had demonstrated the fallacy of this view, and in point of fact it was now well known that the brightest and clearest looking water might contain a deadly organism—a micro-organism, of course—invisible to the unassisted eye, and undiscoverable by chemical analysis. With the advance of the germ theory of disease the necessity for a test which should recognize the absence or presence of these micro-organisms, became an imperative one, and it was but right to say that the credit of the discovery of a reliable test—the biological—was due to a member of the medical profession, Dr. Koch, of Berlin. This test he had the honor of introducing to the notice of the members of this Institution four years ago, and at the same time he exhibited photographs of the results of his examinations of London water, as well as of Manchester water, which the late Dr. Angus Smith was engaged upon. Since then he was glad to find the author of the paper had been diligently at work with Koch's test, both in his laboratory and "in his periodical examinations of the waters supplied to the metropolis." He now submitted for acceptance the general conclusions to which he had been led by his experimental researches in water purification. Mr. Hogg's remarks would be chiefly confined to the biological part of the question. He thought it would be not only convenient, but absolutely necessary, to get a clear insight into the nature of these exceedingly minute organisms before venturing upon or attempting to deal with the more difficult part of the question, their separation from water, by filtration or other process. It must not be supposed that the micro-organisms in question bore any resemblance to those larger organisms

which infested water, many of which could be seen by the unaided eye, as entomostraca, pulex, &c. No idea either of the excessively minute bodies known as bacteria, microbes, &c., would be gained from the magnified pictures which had been thrown on the screen. It could hardly be imagined that those irregular masses, those colonies consisted of hundreds of millions of living micro-organisms. To describe them individually, or rather to speak of them collectively, and as a genus, they measured from the $\frac{1}{5,000}$ to the $\frac{1}{50,000}$ of an inch, their movements being regulated by a motor fiber, a flagellum, placed at the extremity of their bodies, and which measured only the $\frac{1}{200,000,000}$ of an inch. Their outer covering or skin was chiefly composed of cellulose, which enabled them to resist the action of strong acids and alkalies, as well as the variations of temperature, cold and heat. As an example of the former he had repeatedly placed them in strong fuming nitric-acid, and at the end of a week or a month had seen them as lively and apparently as unaffected as they were in their natural element. Life was even more persistent in the germs, spores, or ova, than in adults, and it would be an act of rashness to say when every individual of a colony had been entirely destroyed. If the water in which micro-organisms lived was much agitated, or the supply of food fell short, the colony would invest itself with a gelatinous matrix, and sink to the bottom of the water. Germs, or resting spores, would remain quiescent and concealed for a lengthened period of time. Light was an essential for the development of some species; darkness for others. A free supply of oxygen was required by some, others lived and throve without it. But all must have carbon and nitrogen, and these elements they freely obtained from the organic compounds held in solution or suspension in most waters, especially those polluted by sewage. Micro-organisms pervaded air, earth, and water; indeed were so very ubiquitous, that water seemingly free from them at one period of the day might swarm with them later on. There were very many varieties or species of micro-organisms, bacteria, some of which were believed to be harmless, whilst others were known to be poisonous, pathogenic, or incitative of zymotic disease. From this rapid sketch of their natural history it might be inferred that all attempts at sifting them out, or straining them off, from their natural element, water, must be attended with very unusual difficulties—often entire disappointment. To say that this could be done by filtration was, he thought, scarcely warranted by the results already obtained. At all events, the experiments he had made with the view of water-purification had not been attended with much success. He was then unable to accept the general conclusions which the author had arrived at. He did not doubt that filtration would considerably improve water; but any process, were it filtration, precipitation, or what not, and which merely reduced organic life to a minimum, went only a short way towards water-purification. The one or two colonies, or even the one or two individuals, which any process left behind, was a danger which could not be contemplated without producing a shudder. The difficulty must have been present to the author's mind when he said that "the microscopic living particles . . . possess such an astonishing power of rapid multiplication . . . that within a very short period of time it becomes impossible to form an opinion as to the number of original organisms from which the vast population is descended." Just so; and it was therefore the more surprising he should believe it to be "extremely simple to construct filters which shall possess the power of removing micro-organisms, in the first instance at least." Speaking from a not inconsiderable experience, he had not seen or heard of a filter-bed which might be trusted to remove two thirds of the coarser and larger organisms so generally met with in London waters during the summer months of the year. It appeared then almost impossible that a water-logged filter, or even a new filter-bed, should remove 90 per cent. of micro-organisms so infinitely minute, and so much more difficult to deal with. How very much, then, was the author's warning needed to guard against erroneous and hasty conclusions that even the best filters soon lost their power, and consequently must be frequently renewed. There was still, he was convinced, much to learn with regard to filters and filter-

ing materials, and this came out more strikingly on examining them in detail. Take either filtration, precipitation, agitation, or natural agencies, and none of them effected the perfect purification of water. Partial failure was the rule. The spongy-iron process, by way of example, at the Antwerp Waterworks. It was only two or three sessions ago that this was spoken of as a great success. Where was it now? Displaced by "agitation with solid particles." The same fate had been in store for many other processes. He knew of only one exception to the rule—Clark's lime process. This more nearly approached perfection than any other, and possibly its greater success might, in a measure, be due to the excellence of the water in the first instance, for it could not be denied that deep well-water was the best, and least likely to be contaminated, of any of the waters supplied to London. If examined biologically and microscopically soon after precipitation was completed, it would be found free from organisms of all kinds. Indeed, he had submitted it to a further test, that of keeping bottles of the Canterbury water exposed to a strong light, and a uniformly higher temperature in his study, for a whole year; and then, on testing it biologically, he found it free from all micro-organisms. This, then, to his mind, was the water, and the water process of the future. The author further alluded to the difficulty he experienced in the removal of some classes of organisms over others. This was a difficulty experienced by observers. He also appeared to have a preference for the gelatine-peptine solid medium over that of other modes of cultivation. Mr. Hogg found it necessary to employ occasionally less solid media, and for the reason that certain micro-organisms preferred them, and multiplied more rapidly in them. Among solid media he had a preference for the agaragar and peptone sugar culture. He would remind the author that particular species would only propagate in a medium containing less than 10 per cent. of gelatine. Again, septic microbes remained in a quiescent state in the presence of commoner forms, possibly enemies. There were other points of detail and precautions to be observed, which, if neglected, marred the results of experiments, and gave rise to erroneous conclusions. Some error of observation had, he was inclined to think, been the cause of a misunderstanding with regard to Dr. Koch's cholera bacillus. There was a Comma Bacillus, of a somewhat harmless character, often met with in the human mouth, and in other situations. This was a very different organism. Dr. Koch's bacillus had a certain selective preference for one kind of gelatine cultivation over that of another. Dr. Crookshank, who had bestowed a good deal of attention upon micro-organisms, said of Koch's: "No one, so far as I am aware, has yet been able to demonstrate the existence of a curved bacillus which is entirely similar, both morphologically and biologically, to the (cholera) Comma Bacillus of Koch." The author of the paper would, he feared, think him either very fastidious or very difficult to please with regard to water purification. It was so, he must admit; and this arose from the fact that the longer he studied the question the more difficult it became to reconcile differences of opinion which experimental researches almost invariably gave rise to, in the first instance at least.

Mr. S. C. Homersham said that the author had compared the Thames water supplied by different London Companies one with the other, and had stated that the West Middlesex was the first in order of merit. If, however, water was drawn from a main pipe, say in the Strand, it would be found to be in a very different condition, biologically, from that of water collected at the "dead ends" of service-pipes branching from the main down a steeet bounded by the river. Near to these dead ends, when the water was not in motion, organisms lived and bred, and were to be found in swarms. In the mains, where the water was in motion, there were but few, and more especially where there was a comparatively quick current. It was essential, even with the best water, that the dead ends should periodically—at intervals of not more than seven to fourteen days—be blown out. The water at these dead ends would be found somewhat thick and muddy, and containing thousands of animalcules. It was delusive, therefore, to compare the water of different companies unless it

was known exactly where the waters were taken from, the time of the year they were collected, and other conditions. The number and the species (animal and vegetable) of the living organisms varied greatly in different situations and at different seasons.

Mr. W. Anderson (Erith) thought that the paper should be accepted as a useful installment to knowledge on the important question with which it dealt, although he could not himself agree with the conclusions to which the author had arrived, and considered that there were some fatal defects in the arguments he had adduced. In the first place, it had not been proved that the gelatine method of investigation arrested all the microbes, or even the more objectionable ones. In fact, experience rather tended to show the contrary. Last autumn a commission of chemists was appointed by the Hôtel de Ville of Antwerp, to examine into the quality of the water-supply of that city, for the town was crowded with visitors attracted by the Exhibition, and there was a considerable cholera scare caused by the prevalence of the disease in Spain. The result of that examination was a report (a copy of which would be found in the library) in which it was stated that the water was absolutely sterile to Dr. Koch's test. No bacteria of any kind could be found by the cultivation in gelatine, but by cultivation on slices of potato abundant life was discovered. That showed that the method of Dr. Koch was defective, because it did not necessarily embrace all the life that might be found in the water, and that the conclusions derived from it were therefore fallacious. Then it had not been proved that the indiscriminate destruction of bacteria was an advantageous thing. He supposed that it might be taken for granted that the destruction of some species would be an advantage, but it was a great question whether the wholesale destruction of living organisms in impure water would be beneficial. In olden days, when sailing ships made long voyages, the kind of water preferred was the dirty water of the London dock, because it was found that, although, at first, it was extremely offensive, it gradually cleared, and then kept better than any other kind. That was no doubt due to the fact that the living organisms first of all destroyed the organic matter which was in the water, and by that very destruction destroyed themselves and settled down as sediment on the bottom, leaving the water quite clear, and in a condition to keep any length of time. In that case the living organisms were clearly of great benefit, and it had yet to be proved that it was wise to destroy them. Just as small birds preyed upon insects, and so did more good than they did mischief, it was quite conceivable that some harmless species of microbes preyed upon the injurious species, and it was by that means that water which had been contaminated by the germs of zymotic disease gradually cleared itself and became inoffensive again. He also took exception to the tests by which the author sought to determine the relative efficiency of various filtering media. He thought it would be only reasonable, first of all, to ascertain what was the best state of sub-division, the best depth, the best rate of filtration of any particular medium, and then, having ascertained that, to institute a comparison between the media when working at their best. Instead of proceeding in this manner, however, they had all been taken at the same fineness, the same depth, and approximately at the same rate of flow; or, at any rate, if the flow had been varied, it appeared to have been so accidentally. He did not think it was fair to assume that all the substances tried would act equally well under the same circumstances; and in that respect he thought the argument about the relative efficiency of filtering media was erroneous. As far as iron was concerned he could speak with some authority, because he knew by experience that iron passed through a forty-mesh sieve, and arranged in a layer 6 inches deep, would, in three months, be altogether impervious to water. Iron could not be used as a filtering medium in that way. Mr. Jabez Hogg's statement that the process originally adopted at the Antwerp Waterworks was a failure, was altogether incorrect and misleading. Mr. Bischof's system of passing water through a mixture of gravel and iron was perfectly efficient, and continued to be so for more than three years; but, in the meantime, a method was discovered of attaining the same object by agitation with iron; it proved to be more

economical in working, and to require much less space and capital outlay, and was, on those accounts, adopted when the works had to be extended. He also took exception to the author's conclusion III., "That organized matter is to a large extent, and sometimes to a most remarkable extent, removable from water by agitation with suitable solids in a fine state of division, but that such methods of purification are unreliable." He supposed that the author did not intend to include iron in that statement, because, although iron was used by agitation, the effect it produced upon water did not depend upon any mechanical action, but upon a chemical process, and that it was absolutely permanent was proved by the fact that it had been purifying from 1,500,000 to 2,000,000 gallons of water daily, at Antwerp, for more than a year, and, as far as he could see, there had not been the smallest variation in the results. Whether the author's conclusions held good with reference to gravel, brick bats, and similar inert substances, he was not prepared to say—probably it did; but certainly he thought the author ought to make an exception in favor of iron. He did not think that any one process of treatment was competent, of itself, to deal with impure water; but he was certain that, by taking three out of the four systems to which the author had alluded, it was possible to obtain from water, however impure, not only a perfectly safe, agreeable, colorless, potable fluid, but one which, he believed, was much safer than any natural supply, not excluding even that of deep wells. He had repeatedly shown, both from a biological and from a chemical point of view, that by treatment with iron, a process discovered more than thirty years ago by Medlock, and further developed by Mr. Bischof and Sir Frederick Abel, that a chemical change was produced, and the organic impurities were reduced to one third or one-fourth, that the microbes were either destroyed or entangled in the precipitate, and separated by sand-filtration; the color and the bad taste were also destroyed, and water of a thoroughly good quality was produced, not by one process, but by agitation, chemical action, precipitation, and filtration. When that had been done, the water was put into covered reservoirs or mains, which were absolutely free from risk of external contamination; and he considered that such water was better than any natural supply. The process sounded formidable and complicated, but in reality it was merely ordinary sand-filtration with the Revolving Iron Purifier added. The expense of purification was not materially increased, for the cost of the water at Antwerp delivered into the main under 200 feet pressure did not exceed 7d. per 1,000 gallons, interest on capital not included. All rivers or lakes, however pure, were liable to contamination, and deep wells were by no means free from the danger, for there had been numerous instances in which wells, in the neighborhood of London and other places, had been closed in consequence of the contaminations produced by increased population. The process, therefore, which embraced not one only, but several methods of purification, was capable of producing excellent water from sources which had been hitherto considered unsuitable. He might also speak of the universality of its application; because, although the Antwerp Waterworks had been prominently put forward, that was by no means the only case in which the method had been tried. He had employed it with the waters of the Neva and of the Nile, the sluggish rivers of Holland and Belgium, with the waters of the Seine, and even with the effluent of the Hertford sewage works, with thoroughly satisfactory results. Wherever it had been tried, the result had been the same: the reduction of organic matter to one-third or one-fourth, the destruction of color, of the objectionable taste, and a renewal of organic life. He thought that all would agree that the destruction of chemical impurity was a very important feature, because the microbes could not exist without the nitrogenous substances which formed the organic impurity, and which hitherto had been rightly regarded as of very great importance. Therefore any process which would not only destroy the microbes, but which would also destroy the food upon which they existed, must be a valuable one. He took exception to the paper, because it had a tendency to produce an impression, upon those not well acquainted with the subject, that the power of a filtering medium

to destroy living organisms was the great thing to be considered and was the proper test of efficiency. He did not think it was. He believed that all the circumstances connected with a good water supply must be taken into account. The engineer who neglected the color and taste of water would find that if he had to supply a town in which there was spring or well water of agreeable taste, color, and brightness, even though greatly polluted, that a water company would have a very uphill game if it supplied a yellowish, ill-tasting liquid.

Mr. James Mansergh said the subject was one of great interest to engineers, especially to those engaged in the construction of waterworks. It was a very fitting subject for consideration by the Institution, although, as it was a new development, few of the members might be able to enter into a close discussion of its details. He himself certainly was not. They could not afford, however, to ignore the researches of the chemist, the biologist, and the physiologist, and their thanks were due to the author for the graphic manner in which he had brought forward the results of his experiments. He had had the advantage of being a pupil of his father's several years before the author was born. If he might be allowed, without impropriety, to make a purely personal reference, he should like to state that he had a further special interest in the subject, because he had been for some time experimenting, under the advice of an American physician, on a treatment which had involved the taking of a large quantity of undiluted hot water daily. To such an extent had that been the case, that, taking the basis of the figures which had been given as to the number of microphytes found in the filtered water of certain of the London companies, he found that his share during the last eighteen months had been 23,198,400 individuals, possibly colonies —he hardly knew which. He thought it was clear from that experience that the great majority of these organisms were clearly non-pathogenic, that was, inoperative in the production of disease under ordinary conditions. On the other hand, it was equally certain, from the labors of Pasteur, Dr. Koch, and others, that there did exist organisms which undoubtedly possessed truly pathogenic capabilities. For that reason it was of the utmost importance that biological researches should be prosecuted with vigor, especially in the direction of determining which organisms were dangerous, and which were innocuous. In this country scientific men were, he feared, handicapped by the operations of the anti-vivisection acts—backed up in certain quarters by false and mischievous sentiment—and were unable to carry out their researches to the extent permissible on the Continent. This was very unfortunate, because it was absolutely necessary in such inquiries as Pasteur's to make good each step as it was taken by actual experiment upon some of the lower forms of animal life. He would ask the author, in his reply, to give a little further explanation of the blister like appearance of several of the plates. He had to some extent explained it by saying that certain of the organisms had the power of liquefying the gelatine, but he thought that that might lead to considerable errors in the counting of the numbers. Surely those great blebs must spread over and obliterate many of the small compact colonies which were shown on the diagrams. He would also ask for the author's opinion upon the discoveries of Mr. R. Warington. Mr. Warington had found that there were certain bacteria which effected the nitrification of other organic matter, and that these creatures had their habitat in the upper surface of the soils of manured lands. Those experiments were carried out on the model farm at Rothamsted under Messrs. Lawes and Gilbert. Mr. Warington appeared to have satisfied himself that the nitrification was due principally, if not entirely, to these microbes. If these conclusions were correct, it would appear that the author's suggestion, to drain the beds of the intermittent filtration process for the purification of sewage which he had invented, 6 feet deep, might be materially modified. Impressed with this idea, he had some months ago discussed the matter with Dr. Frankland, and had subsequently advised the preparation of four burnt clay filtration areas on a sewage farm near London, side by side, and of exactly similar size and formation, excepting that the depths were respectively 2 feet, 3 feet 3 inches, 4 feet 6 inches, and 6 feet. These were now being experimented with, and the results

would be interesting as proving or disproving that the shallow beds were as efficient as the deeper.* He was also considering the advisability of importing soil from a farm where the nitrification went on satisfactorily, and sowing it, with its contained bacteria, upon another apparently deficient in those organisms, so as to inoculate the latter into efficiency. Coming back directly to the subject of the paper, it appears to be clear that the microbes in the case of the sewage farm were performing an exceedingly useful function; and he should like to ask the author if it might not be that the majority of the organisms found in potable waters were operating in a similarly beneficent manner.

Mr. E. K. Burstal remarked that the paper was of a purely chemical nature, and that it was somewhat difficult for engineers to grasp its details fully. The tables certainly showed the wonderful effect produced upon water by mere sand-filtration. Only 2 or 3 per cent. of the microphytes remained, but it was not evident whether it was the dangerous ones that had been removed. The healthy condition of London would seem to indicate that that was the case. He certainly took exception to the way in which the "order of merit" had been obtained. In the table at page 326 there were six columns. In the the third column the average storage in days began at 14.7, and therefore the Chelsea Company, having that figure, were credited with the first place. The numbers 1, 2, 3, 4, 5, etc., were purely arbitrary, and ought to be accepted with great caution. The rate of filtration per square foot was the same. Regarding the thickness of sand, there was nothing to show that 4 feet 6 inches were better than 3 feet 3 inches. As to the average number of micro-organisms found in the water, the number for West Middlesex was six, and for Chelsea fifteen, but the author stated that the number in water from a deep well in chalk at Sudbury was twenty-five. After all that had been stated by the author's father and himself, and all the attacks that had been made upon London water, did he mean to imply that sand-filtration rendered the water better and more potable than that obtained from the chalk? If that was the case the new method of examining water would lead to a thorough revolution in the views generally held on the subject. He did not think that a stronger argument in favor of the quality of the water at present supplied to London could be found than that contained in the paper, if the facts stated were correct. Mr. Anderson, however, appeared to think that the gelatine process ought not to be accepted in all respects as a satisfactory one. It would be interesting to know what were the views of chemists on the subject. As he before stated, he could not agree with the order of merit given by the author in regard to the quality of the waters.

Mr. W. W. Beaumont said that although some of the criticisms on the paper had been adverse to the use of the system described, there had not been for a long time before the Institution a paper that was so flattering to engineers in the results which it related. The figures in the paper showed that the Thames water, notwithstanding the character often attributed to it, might be as good as that which was most praised by chemists. The system described had been, it was said, brought to perfection by one who had more laboratory room and materials at his disposal than could be found in the whole of England, and it might therefore be assumed that the figures might be taken as of as much value to engineers as anything the system with its numerous sources of vitiation could give, in enabling an opinion to be formed as to the results of engineers' work. It appeared from the tables that the Kent well-water as supplied contained many more micro-organisms than the Thames water, supplied by the West Middlesex Company. The water from the Kent wells at Deptford contained from six to eight micro-organisms, but as supplied it contained as many as twenty six. If the water from the well to the supply could so gain in pollution it was somewhat remarkable that there was so small a growth of organisms in the water supplied by the river companies, because it must be assumed that the water was purer, as far

* It was a curious coincidence that on the 14th of April, the day after the above remarks were made, a letter appeared in *The Times*, written by Dr E. Frankland from Castellamare, referring to a report on the mode of treatment intended to be adopted by the Metropolitan Board of Works for the London sewage, and stating that whereas in the Rivers Pollution Report he had recommended 6 feet depth of earth for intermittent filtration, he now had reason to believe that 2 feet would be equally effective.

as the organisms were concerned, in proportion to the numbers in the water as it left the filters in the one case and the wells in the other. That did not, however, seem to be the case, for, taking some of the other figures, in the Grand Junction and Chelsea Works the numbers remained very low, and the author had pointed out that those numbers bore some direct relation to the thickness of the filters or of the sand-beds—in other words, to the amount of mechanical action to which the water was subjected. The paper was gratifying to engineers, because it showed that they had for a long time been able to do, with the means at their disposal, as much as chemists and biologists could now teach them to do by their most recent researches, aided by the most complete apparatus. The author, in describing his process, stated that in taking the gelatine from the bottle it was necessary to be very quick in putting it under the glass vessel. If, however, the result of a test could be vitiated by so short an exposure, it was not surprising that the Kent water was found to rise suddenly in impurity from six or eight organisms to twenty-six, as between the well and the company's pipes. That proved that, although the water supplied by the river companies was so good, it would be even better if it could be a constant supply. If the water could be rendered so rapidly impure as the author's remarks appeared to indicate, London people must, as a rule, be drinking water from the ordinary house cisterns that was vitiated largely by organisms.

Mr. W. Morris (Deptford) said he thought the paper most interesting to engineers, as it showed what filter-beds were really doing. He believed that some of the organisms referred to would be found in the waters of all lakes and rivers. After passing through filter-beds there was, as the author had shown, a very great reduction in the number of the organisms, but it would appear that those which remained in the filtered water increased so rapidly that if the water were kept long enough it would be found to contain its original proportion of colonies. If the organisms contained in good potable waters had no influence on health, their number would be of little importance; but, as had been urged by chemists and other scientists, such water might be accidentally contaminated by disease germs or pathogenic organisms derived from excrement or other sources, and to provide against such a contingency it became important to remove the whole of the organisms by filtration, although only a very small percentage might be really injurious. If the present system of filtration had in some cases removed 98.9 per cent. of the organisms, was there not reason to believe that by improved filters even better results might be obtained? The results given by Mr. Anderson of agitation with iron, pointed to another valuable means of purifying water in connection with filtration. The depth of the sand used in filter-beds had been alluded to, but the quality of the sand was also a matter of some importance. There might be a great depth of sand, but if it were not sufficiently fine the result would not be so good as with a smaller depth of a finer and better material. From his experience of the filter-beds formerly in use at the Kent Waterworks, he believed that the deposit of suspended matter, and the growth of vegetation on the surface of the sand, materially assisted in the filtration of the water; as it had to pass through the interstices of much finer strainers than the sand itself. In Berlin it was reported that covered filter-beds were not so efficient in removing these organisms as those which were open and uncovered; the reason for this might be that the covering of the filter-beds checked the growth of the vegetation on the surface of the sand, which would have assisted in the removal of the organisms.

Mr. C. W. Folkard thought that one or two of the speakers had hardly been fair in their criticisms, because the first thing a scientific man ought to do was to follow the truth, and if it was necessary, in some little way, to go back from his opinion, that ought to be done. Four years ago he had read a paper on a somewhat similar subject before the Institution, and he thought that since that time very great strides had been made in the examination of water. He was then strongly of opinion, as he believed most people were, that there was no method by which to determine whether water was wholesome or not. Of course Dr. Koch's method was not perfect, but he thought

chemists were now on the road to a process which would show whether water was really wholesome as distinguished from being chemically pure. As a pupil of the late Dr. Medlock, he thanked Mr. Anderson for pointing out that to the former was due the credit of first drawing attention to the great power of iron in purifying water.

Mr. C. Ekin remarked that one point in the discussion had not been sufficiently elucidated. Mr. Anderson, in alluding to the fermenting process that took place in the case of Thames water taken on board ship in the olden times, and its subsequent wholesomeness, hinted at the possibility of micro-organisms in water being somewhat beneficial in their operation. As a matter of fact, he believed that they were among their best benefactors, for what Mr. Anderson had supposed might take place had actually been proved to do so. In a discussion at the Chemical Society a few weeks ago Dr. Klein, who was an authority perhaps hardly second to Dr. Koch, assured the meeting that the septic organisms were absolutely inimical to the pathogenic organisms that accompanied disease, and not only were they inimical, but they were so much stronger, and their vitality so much greater, that it was not possible for the disease organisms to exist in their presence. With the caution and diffidence of the true man of science, Dr. Klein confessed that there was much that was hazy in the present knowledge of these organisms, and he especially warned chemists against drawing deductions from very incomplete data. The fact of the one set of organisms destroying the other was, however, clear, and its practical importance could hardly be overrated. It explained, too, what had hitherto been a mystery. Many present must have often marveled at the fairly good health of communities drinking waters even grossly polluted. The Thames received quite sufficient pollution, but it was purity itself as compared with several of the rivers supplying some of the northern towns. Now these rivers received the dejecta of thousands of pa ients suffering from typhoid fever, and it was a wonder what possible agency could be at work to prevent the wholesale decimation of the populations subject to these influences. Wherever pollution existed, bacteria swarmed, apparently in some direct ratio to the extent of the pollution. If their presence was fatal to the existence of the organisms accompanying disease, and Mr. Ekin had spoken and written of them for years as playing the part of useful scavengers, then instead of holding them up to opprobrium, they ought to be looked upon as real benefactors. It must not be supposed, however, that he advocated swallowing the scavenger, or that he undervalued efficient filtration. He only wished to caution the meeting against sensational deductions from the presence of the few bacteria that might be found in filtered river waters.

Mr. J. A. Wanklyn said that the subject of the paper was one in which he had been interested for nearly twenty years, and he believed that his views were pretty well known through the medium of his book. His belief was that there was one safe and rational way in which to regard organic matter in drinking water, and that was to assume that it was highly dangerous, and to classify waters according to the proportion of organic matter present. He attached very little importance to searching after organisms in drinking water; indeed, he looked upon such investigations with a great deal of contempt. Eighteen years ago, before the Royal Commission, presided over by the Duke of Richmond, he ventured to say that the London water was cleaner and more wholesome than the water of Loch Katrine. He was laughed at at the time, but now even Dr. Frankland, who at that time talked of mountain air and mountain water, had come to admit that there was more organic matter in Loch Katrine than in certain London waters. With regard to the question of filtration, he held that organic matter could be removed from water with the greatest ease by filtration through many media.

Mr. S. C. Homersham observed that the statements which had been made with regard to taking in water from the Thames for vessels in the docks near London, that it fermented on the voyage, and afterwards became clear and good, were entirely erroneous. He had, many years ago, closely investigated the matter, and was therefore able to speak with confidence on the subject. Mr. Martin, the Engineer to the West India Docks Company, had informed him that many years since the company went to the

trouble and expense of putting up filter-beds to filter the water obtained for this purpose from the Thames; that it was, however, found to become so bad on the voyage that the company gave up using it, and resorted to other water. This had been the case for many years past. Many vessels now obtained supplies of uncontaminated spring-water derived from the chalk at Erith, Gravesend, and other suitable places alongside the Thames.

Dr. Percy Frankland, in reply, said he had been asked to explain more fully than he had already done some of the details of the process of gelatine culture. In the first place the gelatine and peptone mixture did not develop organisms of itself, but they had to be imported into it either from the air or from the water or from some other external source; and then the question had been asked how it was possible to separate the organisms introduced from the water from those introduced from the air during the manipulations which the process entailed. Into the first of those questions it was hardly necessary to enter. Of course it involved the well-known question of the spontaneous generation of life. It had long been fully established that if the media which were capable of nourishing those lower forms of life were sterile, and were then preserved from the access of such low forms of life or their germs, they would remain unchanged for an indefinite period of time. Every pot of jam and tin of meat was an illustration of that principle. The jam or meat was sterilized, and as long as the pot which contained it was not open it remained unchanged; but as soon as aerial organisms gained access various putrefactive and other changes would in time take place. The introduction of organisms from the air probably required more explanation. It was no doubt observed that, in his manipulation, the greatest care was taken that the exposure of the plate to the air should be as short as possible; but even with such exposure there was, at any rate, a risk, especially in a room where there was a good deal of dust, of considerable contamination taking place. In all cases when plates of that kind were put up for examining waters or other liquids, he made a practice of putting up at the same time a plate to which no water had been added, but which had experienced the same exposure to the air as the water-plate. Then if the plate showed any serious aerial contamination, he should expect to find the same in the water-plate, and the experiment would be rejected. To show that under ordinary circumstances that was not the case, he had brought with him a few plates to exhibit to the members. There was an air-plate containing absolutely no organism upon it, and there were two plates with the cultivation of a comma bacillus. If the air had not been as pure as it was on the occasion when the plate was put up, two or three organisms might be found; but in comparison with the ordinary plates that slight experimental error was of very little moment. These aerial organisms could generally be readily distinguished from the organisms derived from the water, because they rested absolutely on the surface, and they were generally moulds, while the organisms found in the water were very rarely moulds. He much regretted that several of the speakers, and notably Mr. Bischof, had imported much into the discussion which had really no relevance to the matter contained in the paper. Mr. Bischof had started with the assumption, and many other speakers had done the same, that he had endeavored to make out a case for the existence of a connection between the abundance of micro-organisms in water and its wholesomeness. That assumption had been made without reference to any particular passage in the paper, and he thought that Mr. Bischof and the other speakers would find some difficulty in pointing out any passage either in this paper, or in any of his previous publications on the subject, in which such a connection was said to exist. He thought that Mr. Bischof had confounded his own previous attitude of mind with Dr. Frankland's, and it was really against himself and his own utterances that his attack should have been directed. From the first, Dr. Frankland's idea had been to apply the gelatine process to an investigation of the much-vexed question of the value of processes of water-purification, which had hitherto rested upon an altogether speculative basis. It was with that view that the experiments he had brought before the Institution were undertaken; it had been with that view that

month by month the London waters had been submitted to examination by that test, and a little consideration would at once render it apparent that that investigation could be carried out without any reference to the influence of those micro-organisms upon health, the problem being simply to ascertain whether and to what extent various processes of purification had the power of removing micro-organisms in general; but the results obtained in such an investigation, made as it had been with the motley assemblage of organisms found in unfiltered river water, in soil extract, or in sewage, obviously had a wider significance, inasmuch as those processes of purification, which were capable of removing such a heterogeneous crowd of microbes, might be safely assumed to be able to deal with any other kind of micro organisms whatever, whether harmless or pathogenic, because neither in their size, nor in their form, nor in their habits could pathogenic organisms be sharply distinguished from non-pathogenic. Thus, in the matter of filtration, there was absolutely no reason to suppose that a pathogenic organism behaved differently from a non-pathogenic organism. He emphatically stated, and he challenged contradiction, that he had never gone beyond that in his conclusions. He had never asserted that water containing a smaller number of micro-organisms was *ipso facto* more pure or wholesome than another water containing more. His paper treated of the removal of micro-organisms in water, and not of the wholesomeness or unwholesomeness of such organisms in general. On the point of removing micro-organisms from water, of which so much used to be said by Mr. Bischof before any satisfactory means of determining such removal was in existence, Mr. Bischof was now ominously silent. In that lay doubtless a key to his acknowledged loss of enthusiasm for the process. He had listened with much interest to the remarks of Mr. Jabez Hogg, concerning the behavior of the organisms; but he was not prepared to endorse the statement that micro-organisms might be preserved in fuming nitric-acid without suffering any discomfort. He had not the slightest doubt that when the micro-organisms were placed under the microscope, they still showed movement; but he ventured to say that if they had been submitted to cultivation in gelatine, or some other nutritive medium, it would have been found that their vitality was lost. Those minute organisms, in common with other minute particles, exhibited a peculiar kind of motion which had nothing to do with vitality. A number of similar experiments, showing the extraordinary powers of resistance which micro-organisms were supposed to possess, had been placed before the Chemical Society some years ago by the late Mr. J. Hatton, who applied no further test to the organisms beyond looking at them under the microscope and seeing them move about. Those tests were of course made before the test of gelatine cultivation, though not before the ordinary broth cultivation, and he thought it was high time that the fallacy of that mode of recognizing the vitality of micro-organisms should be pointed out. Mr. Homersham had stated that it was impossible to compare the various water supplies, inasmuch as the samples might be taken from the dead ends of service pipes branching from the main. All the samples to which he had referred had been taken from places which were expressly recommended by the engineers of each individual company, and he need hardly say that he did not think these gentlemen would recommend the taking of samples from such manifestly unsuitable and disadvantageous places. Of course, if samples were taken from such places the results would be very different. With regard to Mr. Anderson's criticism of the gelatine process in general, and the illustration which he gave of its alleged weakness by referring to the results obtained in Antwerp, he could only say that he could not be responsible for other people's gelatine. He had no doubt that some gelatine, improperly prepared, might not develop organisms at all. Much depended upon how the gelatine was made. He knew the quality of the gelatine which he himself made, but could not be prepared to guarantee the results obtained from gelatine made by anybody else. The mixture to which he had referred was used by Dr. Klein in this country, and by nearly every bacteriologist engaged in the cultivation of micro-organisms It was quite true that the gelatine-pep-

tone medium was not suitable for the cultivation of all micro-organisms, but it was well adapted for the vast majority of known forms. With reference to the criticism as to the rates of filtration at which the various substances had been tested, of course to make the inquiry absolutely complete every conceivable rate should be tried for every individual substance. He thought, however, that the first way of attacking the question was to use the same depth of each substance, and to make the rate as nearly constant as possible, and even that was a matter of great difficulty. One point had been brought forward by Mr. Anderson which he most emphatically challenged—that it was of the greatest consequence to purify water chemically, because, if it was so purified, the organisms, notably the pathogenic organisms, could not exist in it. That was likely to give rise to serious misunderstanding. Although he did not agree with Mr. Jabez Hogg that these organisms were capable of enduring strong nitric-acid, yet he was strongly of opinion, and he knew it as the result of experiment, that pathogenic organisms could be kept for a long period of time alive in pure distilled water. He did not believe that purification by agitation with iron, or by filtration through particles of iron, would render water as pure as distilled water, and he did not think that water which was chemically pure could be considered safe on the ground of micro-organisms if afterwards introduced would not live in it. It had been stated that Dr. Klein had remarked that septic organisms were absolutely fatal to pathogenic organisms; but he certainly did not make such a sweeping statement. He said that there were some experiments which seemed to show that some pathogenic organisms were destroyed by septic organisms. That that took place with the extraordinary rapidity implied by Mr. Ekin's observation was certainly not the case. If some pathogenic organisms were placed in a given medium with septic organisms, and they were allowed to enter into competition, in all probability in the course of time the pathogenic organisms would have disappeared, and the septic organisms would have gained the mastery, but there was no evidence that all pathogenic organisms would behave in that way; and in the present incomplete state of knowledge it was highly undesirable to place any reliance on such fragmentary observations.

Sir Frederick Bramwell, President, said he feared that as a practical body the meeting could not help feeling troubled at the want of result attendant on the paper and its discussion. He thought it was not too much to say that it had been left an open question as to whether the organisms did any harm, whether if some were harmful others were not innocent, whether there were not some organisms which destroyed others, and whether it would not be well to leave the destroyers in the water so that they might destroy. Nobody knew which were the bad and which were the good, or whether the bad would eat up the good, or the good eat up the bad. He would ask anyone (except perhaps Mr. Mansergh, who had swallowed twenty-three millions of organisms without feeling any the worse for it), whether on going home he would be prepared to drink a glass of water, even if treated with strong nitric-acid. He felt in the most complete state of confusion, and more inclined than ever to adhere to the practice of never drinking water unless it had been boiled. Seriously, the paper and the discussion were enough to cause great alarm by showing the danger of drinking polluted water; but having excited this alarm he could not find that any remedy was agreed on by which that alarm might be satisfactorily allayed.

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The total length of the Austro-Hungarian railways in 1885 was 21,980 kilos., against 20,818 in 1884, showing an increase of 1,162 kilos., equal to 5.6 per cent. During the same period the traffic had decreased to the extent of 4.8 per cent. for passengers, 1 per cent. for goods, and the return per kilo. had fallen off by 5 per cent. The gross receipts show an increase of only 0.3 per cent., those for passengers and luggage an advance of 2.7 per cent., whereas the goods traffic declined 0.4 per cent. The reduced rates for goods traffic introduced on many lines was accompanied by a simultaneous decline of the traffic in merchandise and other goods, and both circumstances naturally contributed to a reduction of the gross receipts. The average receipts per kilo. were less than in 1884, a year already distinguished by low average returns. They amounted to 12,223 florins in 1882, 12,268 florins in 1883, 11,718 florins in 1884, and to only 11,135 florins in 1885, and have, consequently, fallen off by nearly 9 per cent. since 1882.

# HYPSOMETRY.

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## I.

§ 1. Hypsometry is that branch of geodesy which treats of the measurement of heights, either absolute when referred to the sea level, or relative between any two points on the earth's surface. There are three principal and independent methods in use.

The first depends upon the law of the decrease of pressure of the atmosphere with an increase of altitude; this method employs the barometer, and may be called barometric leveling. The second depends upon the measurement of the vertical angle and the horizontal distance. It employs an angle instrument, the horizontal distance usually being given by triangulation; the elevation is then determined from the known parts of a triangle, hence the name trigonometric leveling. The third consists in measuring the distance of two points above or below a horizontal line; this is ordinary leveling, in which a leveling instrument gives a visual horizontal line. Notice that the second is the only one applicable when one or both stations is inaccessible. These three methods will be treated separately in succeeding chapters.

§ 2. In a geodesic survey conducted to determine the size and figure of the earth, the vertical element is required, although it is not nearly as important as the horizontal. For example, the profile of the base must be determined so that the measurement may be reduced to a level line, and its elevation above the sea level must be known, that the measurement may be reduced to the level of the sea; in planning the triangulation, at least the approximate difference of level of the vertices of the triangles is required to determine the height to which the signals must be elevated that they may be visible from the other stations.

When the object of the survey is a map, the vertical element is more important; if the map is to serve as a basis of a geological or topographical survey, the vertical element is equally as important as the horizontal element, or perhaps more so. If the map is to be useful in the preliminary examination for railroads, canals, river improvements, etc., the vertical element becomes the most important.

§ 3. Of the three co-ordinates necessary to completely determine a point—1, vertical distance; 2, horizontal distance, and 3, direction—there is the greatest uncertainty in the results for the vertical distance. It is only very recently that leveling has been done with an accuracy that would compare favorably with other geodesic operations. This is partly due to the fact that early geodesic operations were carried on for scientific objects which did not involve the vertical element, and partly to the natural difficulties, which will be discussed presently.

### Chapter I.

### LEVELING WITH MERCURIAL BAROMETER.

§ 4. *Barometric Leveling in General.*—The difference in height of two places may be determined by finding the difference of their depths below the top of the atmosphere. The height of the atmosphere above any point is determined by weighing it; this is done by trying how high a column of mercury or other liquid the column of air above it will balance, or by finding the pressure it will exert against an elastic box containing a vacuum, or by observing the temperature at which a liquid boils, *i. e.*, by observing the temperature at which the pressure of the atmosphere just balances the tension of the vapor. This gives rise to three slightly different methods, according to whether the instrument is a mercurial barometer, an aneroid, or a thermo-barometer or boiling point apparatus.

Barometric leveling is specially adapted to finding the difference of level between points at considerable horizontal or vertical distance apart. Under these conditions it is the most speedy, but the

least accurate of any of the methods of leveling. It is very valuable in making geographical surveys of large areas for determining the elevation of stations to be occupied by the topographer. It is also well suited to making a reconnoissance for a railroad, or for a scheme of triangulation.

### Sec. 1. The Instrument.

§ 5. *Description.*—There are two kinds of mecurial barometers, the cistern and the syphon; the former is the best and most reliable for hypsometrical purposes. The general form of the cistern barometer needs no description; Fig. 1 shows the cistern and details at the lower end

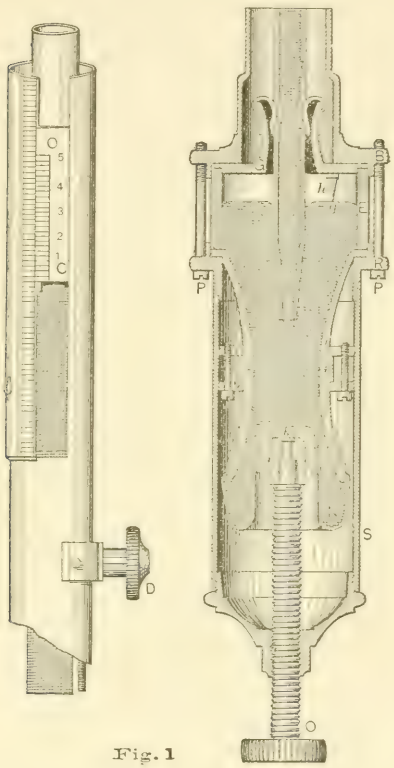



Fig. 1

of the instrument. "The cistern made up of a glass cylinder F, which allows the surface of the mercury to be seen, and a top plate G, through the neck of which the barometer tube *t* passes, and to which it is fastened by a piece of kid leather, making a strong but flexible joint. To this plate, also, is attached a small ivory point *h*, the extremity of which marks the commencement or zero of the scale above. The lower part, containing the mercury, in which the end of the barometer tube *t* is plunged, is formed of two parts *i j*, held together by four screws and two divided rings *l m*. To the lower piece *j* is fastened the flexible bag N, made of kid leather, furnished in the middle with a socket *k*, which rests on the end of the adjusting screw O. These parts, with the glass cylinder F, are clamped to the flange B by means of four large screws P and the ring R; on the ring R screws the cap S, which covers the lower parts of the cistern, and supports at the end of the adjusting screw O. G, *i*, *j*, and *k*, are of boxwood; the other parts of brass or German silver. The screw O serves to adjust the mercury to the ivory point, and also, by raising the bag, so as to completely fill the cistern and tube with mercury, to put the instrument in condition for transportation."*

§ 6. *Filling the Barometer.*—It is no slight matter to properly fill a barometer. It can best be done by the manufacturer, who has all the facilities; but as it is sometimes necessary for the observer to refill it, the following hints are given. Tubes require refilling owing to the breaking of the glass or to the entrance of a bubble of air.

The mercury should be chemically pure and free from oxide; otherwise it will adhere to the glass and tarnish. Moreover, if it is not pure, the height of the barometric column will not be correct; only mercury should be used which has been purified by distillation. For the best results, the mercury should be boiled in the tube to expel moisture and air; but this cannot always be done, and fair results can be obtained without boiling. The following description of the method of filling is from Smithsonian Report, 1859, page 440, and is recommended by Williamson (p 140).

"The glass tube, which should be clean and dry, must have its open end ground straight and smooth, so that it can be closed air-tight with the finger, which should be covered with a piece of chamois or kid skin. Warm well both mercury and glass tube, and filter in through a clean paper funnel with a very small hole (about $\frac{1}{50}$ of an inch) below,

* Smithsonian Mis. Col., Vol. I.

to within one-fourth of an inch of the top. Shut up the end and turn the tube horizontal, when the mercury will form a bubble that can be made to run from end to end by change of inclination, which will gather all the small air bubbles visible that adhered to the inside of the glass tube during filling. Now let that bubble, which has grown somewhat larger, pass to the open end. Fill up this time with mercury entirely, and shut tightly. Then reverse the tube over a basin, when, by slightly relieving the pressure against the end, the weight of the column of mercury will force some out, forming a vacuum above, which ought not to exceed one-half an inch. Closing up again tightly, let this vacuum bubble traverse the length of the tube on the several sides, when it will absorb those minute portions of air, now greatly expanded from removed atmospheric pressure, that were not drawn at the first gathering. The perfect freedom from air is easily recognized by the sharp concussions with which the column beats against the sealed end, when, with a large vacuum bubble, the horizontally held tube is slightly moved."

"A barometer so prepared will probably read lower by a few thousandths than if the tube had been boiled, but in a stationary barometer its error will probably not soon change, and carrying on horseback will be apt to improve it rather than otherwise, as it is then carried with the cistern uppermost, and the bubbles will be jolted toward the open end."* If possible it should be compared with a standard barometer.

§ 7. "To fill a tube by boiling, an alcohol lamp is needed, although it can be done over a charcoal fire. The lamp being filled and put in order, begin to fill the tube by pouring in through the funnel as much warm mercury as will occupy about five inches; then, holding the tube with both hands above the mercury, heat it gently, and let it boil from the surface of the mercury downward to the end of the tube, and then back again, chasing all of the bubbles of air upward. A little practice will make this easy, the tube being held a little inclined from the horizontal, and constantly and rapidly revolved, always in the same direction, so that every portion of the metal may be heated gradually and uniformly. After this has been done, let the tube cool sufficiently to admit of its being held by the gloved hand, and then pour in enough warm mercury to occupy several inches more of the tube, which may now be held with both hands, one above and the other below the heated portion. After boiling this thoroughly free from air, repeat the same operation with more mercury added, until the tube is filled to the end. With care and practice the mercury may be boiled entirely free from air up to within an inch or less of the end of the tube. A tube filled in this way may have, in every respect, as perfect a vacuum as one prepared by a professional instrument maker."†

§ 8 In extended barometric operations in the field, a supply of extra tubes is carried, to be used in case a tube is broken. These tubes should be drawn out so as to be a little longer than they are required to be when fitted into the barometer. The open end should be cut off to such a length that it shall always be immersed and yet not interfere with the rise of the lower part of the cistern. When the instrument is finally put together, the cork in the upper end of the brass case should be adjusted so as to hold the closed end of the tube firmly.†

§ 9. *Cleaning the Barometer.*—It frequently happens that the mercury in the cistern becomes so dirty that the ivory point, or its reflection in the mercury, can no longer be seen; this often occurs even though the barometer be in good condition in every other respect. The instrument can be taken apart and cleaned with safety and without changing in the slighest degree the zero of the instrument.‡ Everything used in the operation must be clean and dry. Avoid blowing upon any of the parts, as the moisture from the breath is injurious.

"Screw up the adjusting screw at the bottom until the mercury entirely fills the tube, carefully invert, place the instrument firmly in an upright position, unscrew and take off the brass casing which encloses the wooden and leather parts of the cistern. Remove the screws, and lift off the upper wooden piece to which the bag is attached; the mercury

* Williamson on the Barometer, p. 140.
† Williamson, p. 138. ‡ Williamson, p. 136.

will then be exposed. By then inclining the instrument a little, a portion of the mercury in the cistern may be poured out into a clean vessel at hand to receive it, when the end of the tube will be exposed. This is to be closed by the gloved hand, when the instrument can be inverted, the cistern emptied, and the tube brought again to the upright position. Great care must be taken not to permit any mercury to pass out of the tube. The long screws which fasten the glass portion of the cistern to the other parts can then be taken off, the various parts wiped with a clean cloth or handkerchief, and restored to their former position."

"If the old mercury is merely dusty, or dimmed by the oxide, the cleaning may be effected by straining it through chamois leather, or through a funnel with a capillary hole at the end, of a size to admit of the passage of but a small thread of the metal. Such a funnel is conveniently made of letter paper. The dust will adhere to the skin or paper and the filtered mercury will present a clean and bright appearance. If chemically impure, it should be rejected, and fresh, clean mercury used. With such clean mercury the cistern should be filled as nearly full as possible, the wooden portions put together and securely fastened by the screws and clamps, the brass casing screwed on, and the screw at its end screwed up. The instrument can then be inverted, hung up, and readjusted. The tube and its contents having been undisturbed, the instrument should read the same as before."*

With the instrument before the operator, these instructions are easily understood. If a little mercury has been lost during the operation, and there is none at hand to replace it, no serious harm has been done; but if much is lost, the open end of the tube may become exposed in inverting the instrument, in which case air may enter. In this case, as in using and caring for any instrument, a little care and a thoughtful inspection of the method of construction is worth more than any written description.

§ 10. *Transporting the Barometer.*—"In transporting a barometer, even across a room, it should be screwed up, and carried with its cistern uppermost. For traveling, it should be provided with a wooden and leather case. In steamboats or railroads it should be hung up by a hook in the stateroom or car. In wheeled vehicles it should be carried by hand, supported by a strap over the shoulder, or held upright between the legs; but it should not be allowed to rest on the floor of the carriage, for a sudden jolt might break the tube. If carried on horseback it should be strapped over the shoulder of the rider, where it is not likely to be injured, unless the animal is subject to a sudden change of gait. When about to be used it should be taken from its case, while screwed up, gently inverted and hung up, when it can be unscrewed. While it has its cistern uppermost the tube is full, is one solid mass of metal and glass, and not easily injured; but when hung up, a sudden jolt might send a bubble of air into the vacuum at the upper end of the tube, and the instrument would be useless until repaired."*

§ 11. *Reading the Barometer.*—Read the attached thermometer first; it is more sensitive than the barometer, and the heat of the body affects it, while the barometer is not affected. The thermometer should be read as closely as possible, for a difference of 0.1°F is equivalent to about 3 feet in altitude; parallax should be carefully avoided in reading the thermometer.

Then bring, by means of the adjusting screw at the lower end of the instrument, the ivory point just touching the mercury in the cistern. If there is a line of light visible between the point and mercury, the instrument is set too low; if neither a line of light nor a depression can be seen, the adjustment has been correctly made. When the mercury is bright, a shadow of the point can be seen, and if the shadow and the point itself form a continuous unbroken line, there can be no line of light. It is usually best to lower the screw till a distinct line of light can be seen, and then gradually raise it until the light disappears. Before making the final adjustment, tap the barometer a little just above the cistern, to destroy the adhesion of the metal to the glass. Complete the contact of the mer-

* Williamson, p. 137.

* Williamson, p. 134.

cury and the ivory point, at the same time being certain that the barometer hangs freely, *i. e.*, vertically.

Next, tap the barometer gently in the neighborhood of the top of the mercury column to destroy the adhesion of the mercury; this is very important, since raising or lowering the mercury in the previous operation materially affects the form of the upper surface. Then take hold lightly of the brass casing of the barometer, not near the attached thermometer, so as not to unnecessarily heat either the case or the thermometer, and by means of the mill-head screw near the middle of the tube, bring the front and back edge of the vernier into the same horizontal plane with the top of the mercury in the tube, just touching it and no more, and then remove the hand. Move the eye about, and if, in any position, a line of light can be seen between the mercury and the vernier, the latter must be moved down a little; if there is no line of light, but a large space is obscured, the venier must be moved up a little. As the top of the column is more or less convex, when the adjustment is correctly made a small place is obscured in the center, when the light is seen on either side.

Finally having adjusted the instrument as above, it may be read at leisure. On the best barometers the scale is usually divided to inches, tenths, and half-tenths; the vernier reads to one twenty-fifth of half-tenths ($\frac{1}{25}\times 0.05$) or two-thousandths (0.002).

## Sec. 2. The Theory.

### A. common or statical formula.

§ 12. *Fundamental Relations.*—Suppose A and B, Fig. 1, to represent two stations, and that it is required to determine the vertical distance between them; A and B are not necessarily in the same vertical line. Let C represent any point in A B, and D a point a small distance below C. Suppose the pressure per sq. inch at D to be represented by P, and the difference in pressure between C and D by $d$ P. Let $a$ = the weight of a cubic inch of air under the conditions of presure, temperature, etc., existing between C and D; X = the elevation of A above B, in feet.

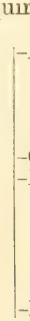


Fig. 2.

It is clear that the increase in pressure from C to D is equal to weight of a column of air between C and D whose cross section is 1 sq. in.; or,

$$a\,dx = d\,\mathrm{P} \qquad (1)$$

§ 13. If $a_0$ = the weight of a cubic inch of dry air at the sea-level in latitude 45° at the freezing point when the barometer stands at 29.92 inches, and $\mathrm{P}_0$ = the pressure under which $a_0$ is determined, then by Boyle and Marriott's law

$$a : a_0 :: \mathrm{P} : \mathrm{P}_0;$$

or
$$a = a_0 \frac{\mathrm{P}}{\mathrm{P}_0} \qquad (2)$$

If H and $\mathrm{H}_0$ represent the heights of the barometer, assuming the temperatures to be the same, corresponding to the pressures P and $\mathrm{P}_0$ and $m$ = the weight of a cubic inch of mercury, then

$$\frac{\mathrm{P}}{\mathrm{P}_0} = \frac{\mathrm{H}m}{\mathrm{H}m_0} = \frac{\mathrm{H}m}{29.92m} \qquad (3)$$

and
$$a = a_0 \frac{\mathrm{H}}{\mathrm{H}_0} = \frac{a_0 \mathrm{H}m}{29.92m} \qquad (4)$$

The weight of a cubic inch of air for any other temperature $t$ is

$$a = \frac{a_0}{m_0} \frac{\mathrm{H}m}{29.92} \frac{1}{(1+ct)} \qquad (5)$$

in which $c$ is the coefficient of expansion of air. For any latitude $\varphi$, (5) becomes

$$a = \frac{a_0 \mathrm{H}m}{29.92m} \frac{1}{(1+ct)} \frac{1}{(1+0.0026\ cos\ 2\varphi)}$$

very nearly. (6)

§ 14. Substituting the value of $a$ from (6) in (1), and $m d\mathrm{H}$ for $d\,\mathrm{P}$, we have

$$dx = 29.92 \frac{m_0}{a_0} (1+ct)(1+0.00260\cos 2\varphi) \frac{d\mathrm{H}}{\mathrm{H}}$$

which integrated between the limits H′ and $\mathrm{H}_1$, the heights of the barometer at A and B respectively gives

$$X=29.92\frac{m}{a_0}(1+ct)(1+.00260\cos.\ 2\varphi)\ N\log.\frac{H'}{H_1} \quad (7)$$

Assuming the mean of the temperature of the air at A and B to be the mean temperature of the air between A and B, we may put

$$t=\frac{T'+T_1}{2}, \qquad T' \text{ and } T_1$$

being the temperatures of the air at A and B. Making this substitution and passing to common logarithms,

$$X=5.74\frac{m}{a_0}\log.\frac{H_1}{H}\left(1+c\frac{T'T_1}{2}\right)(1+0.0026.2\cos.\ \varphi) \quad (8)$$

This formula includes the principal relations involved in determining difference of height with the barometer. The final formula to be used in practice has been given differently by different investigators, according to the values chosen for the constants, to the individual preference for one form over another, and to the degree of refinement desired. A few of these special formulæ will now be considered briefly.

§ 15. *The Constants.*—The value of the term $5.74\ldots.\ \frac{m}{a_0}$, generally known as the barometric coefficient, will depend upon whose values of the densities of air and mercury are used. Boit and Arago found* $\frac{m_0}{a}=1046.7$, which makes the barometer coefficient 60,096.3 ft. (18,317 meters). Regnault's values* which are the most recent and probably the most accurate, give 60.384 feet (18,404.8 meters). Raymond (1803 found* the value of the barometric coefficient by determining the value it should have to make the results by the formula agree with those furnished by trigonometrical leveling; the value obtained in this way is 60,158.6 ft. (18,336 meters). Even under the most favorable circumstances, the observations, eight in all†, were too few to determine such a coefficient with sufficient accuracy; for reasons which will appear in this and Chapter IV., it is highly probable that Raymond's coefficient is the least accurate, although it has been more frequently used than either of the others.

The term $\left(1+c\frac{T'+T_1}{2}\right)$ is known as the temperature term. $c$ is the coefficient of expansion of air, and is equal to 0.00375 per $1^\circ c$; it is usually approximated at 0.004. If this value be substituted, the temperature term becomes $\left(1+\frac{2\,(T'+T)_1}{1000}\right)$ for centigrade degrees; if $T_1$ and $T'$ are given in Fahr. degrees, it is easily seen that the temperature term becomes $1+\frac{T_1+T'-64}{900}$

The term $(1+0.00260\ \cos.\ 2\varphi)$ is known as the latitude term. A few formulæ still contain an older and less accurate coefficient of cos. $2\varphi$ than the above.*

§ 16. *Laplace's Formula.* — Laplace was the first to give a rational formula for determining heights by the barometer, and his formula has served as a basis for several others. It differs from equation (8) as above in having a correction for the variation of gravity in the vertical. If the altitude of the lower station about the sea-level be represented by $z$, then the weight $a$ at the sea-level as given by (6) must be multiplied by $\frac{R^2}{(R+z+x)^2}$ to make it true for any altitude. This leads to an equation which can be integrated approximately by developing the above factor into a series. All the approximations leading to Laplace's form are not easy to discover, and the importance of the matter does not warrant a long search. Laplace's complete formula is†

$$X=60158.6\log.\frac{H_1}{H'}\left\{\begin{array}{l}\left(1+\frac{T'+T_1-64}{900}\right)\\(1+0.0026\cos.\ 2\varphi)\\\left(1+\frac{X+52252}{20886860}+\frac{z}{10443430}\right)\end{array}\right. \quad (9)$$

In which X is in feet and the temperatures in Fahr. degrees; X in the last term is the value of the preceding part of the formula.

Since the entire correction for the

* Smith, Miscel. Col., Vol. I., Pt. IV., p. 9.
† U. S. C. & G. R., 1881, p. 235.

* U. S. C. & G. R., 881, page 227, eq (6).
† Williamson, p. 164; Guyot's Col., etc.

variation of gravity is always quite small, and since at best the barometer can be read only to thousandths of an inch, which corresponds to about 10 ft. of altitude, the latitude term and also the term for variation of gravity with the altitude may be neglected without materially affecting the accuracy of the results. Farther on it will be shown that the appearance of extreme accuracy by retaining these terms can be regarded only as a mathematical illusion, inapplicable to any real state of practice.

§ 17. *Babinet's Formulæ.*—The following formula* by Babinet has no term for the variation of gravity. It is sometimes claimed† that the barometric coefficient was adjusted to meet this correction; from the nature of the case this cannot be true, except for some assumed mean. However, notice that the coefficient is larger than any previously given, see §15. The formula is, for X in feet, and Fahrenheit degrees,

$$\text{Xft.} = 60334 \log.\frac{H_1}{H'}\left\{1+\frac{(T'+T_1-64)}{900}\right\} \tag{10}$$

If H′ and $H_1$ do not greatly differ it can readily be found that

$$N \log.\frac{H_1}{H'} = 2\frac{H_1-H'}{H_1+H'}$$

Making this substitution in (10) gives Babinet's approximate formula

$$\text{Xft.} = 52{,}400\ \frac{H_1-H'}{H'+H'}\left\{1+\frac{(T'+T_1-64)}{900}\right\} \tag{11}$$

"The error involved in the above formula is inappreciable for elevations less than 3,000 feet." ‡

The following§ is essentially the same as Babinet's approximate formula except the value of the barometric coefficient and the form of the temperature term

$$X = 54500 + \frac{T_1+T'-110}{900} \mp \frac{X}{200} \pm 10 \text{ ft.} \tag{12}$$

The last two terms show the degree of reliance to be placed upon the result.

§ 18. *Correction for Temperature of Barometer.*—In all that has preceded, it has been assumed that the two barometers were at the same temperature, which assumption will rarely or never be true. Therefore the heights of the barometer, before being inserted in the preceding formulæ, must be reduced to the corresponding heights which they would have at a common temperature, or a term must be included in the formulæ themselves to correct for the difference in temperature of the barometers. Both methods are employed.

The expansion of mercury for 1°F. is 0.000,1000, and that of brass, of which the scales are generally made, is 0.0000,104; the difference, the relative expansion of mercury is .000,896. For the centigrade scale this difference is 0.00016141. Hence if $h'$ represents the height of the barometer at the upper station, reduced to the temperature of the lower, and $t'$, $t_1$ the temperature of the barometers at the upper and lower stations respectively, we have

$$h' = H'[1-d(t'-t_1)], \tag{13}$$

in which $d$ stands for one of the above differences, according to the kind of thermometer used.

§ 19. Instead of reducing one barometer to the temperature of the other, both may be reduced to any other temperature assumed as a standard; the freezing point of water is generally chosen. Equation (13) is still applicable, provided $t_1$ be considered as representing the temperature of melting ice (32°F. or 0°C), and $t'$ the reading of the attached thermometer. The formula for reduction must now be applied to both readings of the barometer. Numerous tables have been computed for facilitating this reduction; see Guyot's Collection, 3d Edition, Group C., pp. 61–127; Group D., pp. 30, 46, 53, etc.; Lee's Tables, 3d Ed., pp. 152–9; Williamson on the Use of the Barometer, pp. 1–64 of the appendix, etc.

§ 20. The correction for the difference in temperature of the barometers may be made by inserting a term in the general formula. Thus, in (8), it is only necessary to multiply H′ by $[1-d(t'-t_1)]$ to reduce H′ to the corresponding height at the temperature of the lower barometer. Making this correction, using Babinet's barometric coefficient (§ 17) and

* Smithsonian Miscel. Col., Vol. I, Part IV. (Guyot's Collection), page 68.
† Ibid page 9.
‡ Ibid, p. 68.
§ U. S. C. & G. R., 1876, p.p. 352-3; see also Lee's Table, p. 151 (3d ed).

approximating $d$ (.000.896) at .0001, we get *Bailey's Formula.**

$$\text{Xft.} = 60346 \log.\frac{H_1}{H'} \left\{ 1+\frac{T'+T_1-64}{900} \right\} \frac{1}{1-.0001\ (t'-t_1)} \left\{ 1\times 0.0026 \cos. 2\varphi \right. \quad (14)$$

§ 21. *Correction for Humidity.*—In deducing the preceding formulæ, it was assumed that the atmosphere was composed exclusively of dry air; really it is a mixture of air (oxygen and nitrogen), carbonic acid, and watery vapor. The carbonic acid is very small and nearly constant, and hence it need not be considered here; but the watery vapor is both large and variable. If dry air and aqueous vapor had even nearly the same density under the same conditions, the presence of the latter would not affect the problem; but watery vapor is only five-eighths as dense as dry air, and the weight, $a$, of a unit of volume of the atmosphere will depend upon the relative amount of vapor which it contains. Accurate hypsometry accordingly demands that some account shall be taken of the aqueous contents of the atmosphere, and a humidity term has been included in many barometric formulæ.

The introduction of a humidity term in the barometric formula requires that the hygrometric state of the air column shall be known. Accordingly an observation with the hygrometer is made at each station. For this purpose the wet bulb hygrometer or psychrometer is generally preferred, because of its greater accuracy and convenience; knowing the readings of the wet and dry bulb thermometers, the barometric pressure due to the aqueous vapor in the air may be determined from tables,† which are the results of experiments. The observed heights of the barometer may be corrected for the pressure of the aqueous vapor before substituting them in the formula; or the observed heights may be used uncorrected, and the resulting altitude be multiplied by a factor to correct for the humidity. The latter method seems to be generally preferred.

"In a very general sense, in temperate climates near the sea level the amount of vapor in the atmosphere is from 0.2 to 0.4 of an inch, or about one-hundredth of the whole."

§ 22. Bessel was the first to propose the introduction of a correction for the effect of moisture. Plantamour's formula,* which differs from the one proposed by Bessel only in the form and the value of the constants adopted, and Rhulmann's formula† are frequently used and are representative of this class. Williamson‡ has translated Plantamour's formula into Laplace's form [9].

§ 23. It is doubtful whether any considerable increase of accuracy is obtained by including a separate correction for the aqueous vapor.§ The laws of the distribution and transmission of moisture through the atmosphere are too little known, and its amount, especially in mountain regions, is too variable and depends too much upon local winds and local condensation, to allow a reasonable hope of obtaining the mean humidity of the layer of air between the two stations by means of hygrometrical observations taken at each of them. The difficulty lies in getting the mean humidity of the vertical column between the two stations. The observations for humidity are made in the stratum of air next to the surface of the earth, which probably contains the greatest amount of moisture, and which is therefore least representative of the vertical column between the two stations. At any rate, the gain, if there is any, is not sufficient to compensate for the extra trouble in making the observations and the undesirable complication of the formula.

The question of the desirability of applying a correction for the hygrometric state of the atmosphere is so intimately connected with the phase discussed in division B of this section, which immediately follows, that nothing farther need be said here.

§ 24. *Conclusion.*—The preceding do not comprise all the formulæ which have been proposed for barometric leveling, but include the more common ones, and illustrate all the principles involved, except those discussed in division B. Some

* Guyot's Collection, D, p. 69.
† Williamson on the Barometer, Table C, of the Appen.; Guyot's Col., Group B., pp. 46-72, pp. 102-6.

* Guyot's Coll., D., p. 72
† 3 U. S. C. S. R., 1876, p 350.
‡ On the Barometer, pp. 100-6 of the appendix.
§ Guyot's Collection, D., p. 33.

of the omitted formulæ are approximate, some have empirically determined pressure coefficients, etc. Owing to the limitations discussed in the next division, "it matters comparatively little which of the generally recognized barometric formulæ is used."

### B. Dynamical Formulæ.

§ 25. *Defects of Statical Formulæ.*—All the formulæ referred to above are dependent upon the assumption that the air is in a state of statical equilibrium. If a condition of statical equilibrium were possible, we might suppose that the whole atmosphere was arranged in a system of horizontal layers, each of which would be denser than the one above it and rarer than than the one below, each being uniform throughout in temperature and humidity. The temperature and humidity might vary from stratum to stratum uniformly, or according to some more complicated law.

The fundamental assumption in deducing the preceding class of formulæ is, 1, that a difference of pressure is due only to a difference of elevation; 2, that the temperature of the air varies uniformly from one station to the other; and 3, that the temperature of the air between the two stations is the same as that of the vertical column between the horizontal planes of the two points. The introduction of a correction for humidity involves essentially the same assumptions as the temperature term.

§ 26. The air is never in a state of statical equilibrium, but is perpetually undergoing local changes of pressure, temperature and humidity. "For example, the sun, which is the ultimate source of all disturbances, shines only by day. While it shines a certain amount of heat is imparted to the whole atmosphere, but a much higher temperature is given to the ground, and is communicated to the contiguous layer of air. At night the atmosphere loses heat by radiation to space, but the ground loses it still more rapidly and imparts its low temperature to the lowest stratum of air. The lower strata, therefore, have exceptional warmth by day and exceptional coolness by night. If the air is moist it intercepts a greater quantity of solar heat than if it is dry, so that a less quantity reaches the ground, while at night atmospheric moisture checks radiation from the ground. The power of the earth's surface to receive or store or part with heat varies with its character. Naked rocks and cultivated fields, bare earth and grass, forest and snow are affected very differently by the heat rays of the sun, and exert equally diverse influences on the adjacent air, so that one tract of land is often in a condition to heat the air while an adjacent tract is cooling it. Then, too, the sun's heat is unequally distributed through the year; outside the tropics there is a progressive accumulation of heat through summer and a progressive loss through winter. The ocean undergoes less change of temperature than the land, and its rate of change is slower, so that there is frequent, and indeed almost continuous, contrast of condition between it and the contiguous land. As a result of all these influences, together with others that might be enumerated, the equilibrium of the air is constantly overthrown, and the winds, which tend to readjust it, are set in motion.

The temperature of the air is continually modified by external influences; the static order of densities is broken and currents are set in motion; and the circulation and the inequalities of temperature conspire to produce inequalities of moisture. Every element of equilibrium is thus set aside, and the air is rendered heterogeneous in density, temperature and composition."*

§ 27. A consideration of these facts will show the inaccuracy and insufficiency of hypsometric formulæ founded upon an assumed state of static equilibrium. Some of the defects of statical formulæ will be considered in detail before discussing formulæ which seek to overcome these difficulties.

§ 28. *Gradient.*—Let A, B and C designate three barometer stations. Let A′, B′ C′ designate points vertically above each at which the pressure is the same or common. The plane passing through A′ B′ C′ is then a surface of equal pressure; if the air were in a state of equilibrium, it would be a level plane, but in fact it will be inclined in some direction. This inclination is called the *barometric gradient.*

Instead of considering only three

* G. K. Gilbert, in U. S. Geological Report for 1880-1.

points, "we can in imagination project through the air a surface containing all points which have the same pressure; if the atmosphere were at rest, this surface would be a horizontal plane, but under the actual conditions it is never a plane and is ever undulating." For small areas under ordinary conditions, this surface would probably not differ much from a plane.

Conceive another surface passed through all points at which the pressure differs from the preceding one by any constant quantity. With atmospheric equilibrium all such surfaces would be both level and parallel, but in the actual case none are level and no two are precisely parallel. When widely separated surfaces are compared, the variations from parallelism are often so great that their inclinations above the same locality have opposite directions. The atmospheric gradient at the surface of the ground may therefore differ greatly in amount and direction from the simultaneous gradient at a considerable altitude above the same spot.

§ 29. The necessity of considering the barometer gradient is apparent when it is remembered that the air is continually in a state of motion, as is shown in the variation of the height of the barometer. For example, if A and B are two stations, and the atmosphere at rest, then the surface of equal pressure, BC, is a horizontal plane; and AC is the difference of elevation which would be obtained by applying any one of the preceding barometric formulæ. If the air is not in static equilibrium, the pressure at A will be greater or less than before, and the surface of equal pressure may lie above or below BC; if the pressure at A is greater than the average, the surface of equal pressure is above C, say at E, and AE is the corresponding difference of elevation obtained by applying a statical formulæ.

The problem is farther complicated by the fact that the air above B also is in a state of oscillation. If the variations in pressure at the two stations were simultaneous and alike in amount, no error would be produced by the barometer gradient; but these conditions are seldom or never realized.

§ 30. The variations in atmospheric pressure, and the consequent variations of gradient, are so complicated that it is impossible to trace the relation between cause and effect; but there are two variations that are pretty well understood. One has a daily period, and is caused by the variation in the heating effect of the sun between day and night; the second has a yearly period, and is caused by the variations of the sun's heat at different times of the year.

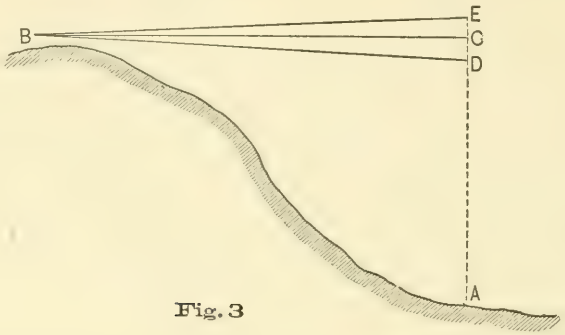


Fig. 3

§ 31. *Diurnal Gradient.*—It is a fact familiar to meteorologists that the pressure of the air everywhere undergoes a daily oscillation. The gradient introduced by this daily change is called diurnal gradient. The pressure has two maxima and two minima which are easily distinguishable. Near the sea-level the barometer attains its maximum about 9 or 10 A. M. In the afternoon there is a minimum about 3 to 5 P. M. It then rises until 10 to midnight, when it falls again until about 4 A. M., and again rises to attain its forenoon maximum; the day fluctuations are the larger.

The daily oscillation is subject to

variations in character and magnitude. The oscillation is greatest at the equator and diminishes toward the poles, but is not the same for all places of the same latitude. Within the United States it varies between 40 and 120 thousandths of an inch. Changes of altitude often cause a marked variation in the amount and character of the diurnal oscillation. The difference which pertains to latitude does not materially affect the ordinary hypsometric problem, but the difference depending on the altitude has a very important effect.

§ 32. *Annual Gradient.*—The annual progress of the sun from tropic to tropic throws a preponderance of heat first on one side of the equator and then on the other, which produces an annual cycle of changes in the pressure and gives rise to what has been called the annual gradients. The amount of this variation is quite small near the equator, but increases rapidly toward the poles; "at the equator it rarely exceeds $\frac{1}{4}$ of an inch per year, while in the polar regions it is often as much as 2 or 3 inches in a few days."*

§ 33. *Non-periodic Gradients.*—In addition to the diurnal and annual variations in the pressure, there are others due to the same general cause, the heat of the sun, but so modified by the local conditions—topography, the humidity, winds, storms, etc.—as to make it impossible to discover the law of their action. These non-periodic variations are much greater in amount and more rapid in their actions than either of the others.

§ 34. *Temperature of Air.*—"It has just been explained that the variations of pressure are due primarily to inequalities of temperature; it will now be shown that, if differences of elevations are determined by the formulæ commonly used, the temperature is directly responsible for other and generally more serious errors." They arise from the difficulty of determining the temperature of the vertical column of air between the two stations.

Let A and B (Fig. 4) be two stations the difference of elevation of which is to be obtained from observations of the barometer and thermometer made at each. Let it be assumed that the pressure observed at B is the same as

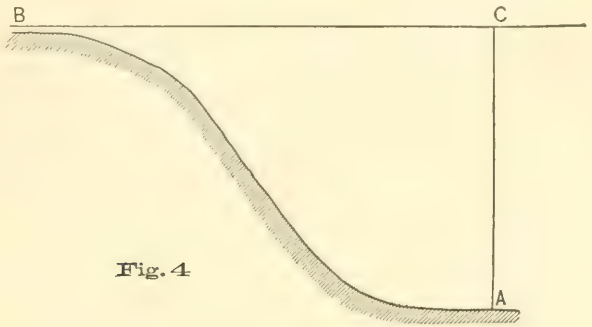



Fig. 4

that at C vertically over A and on a level with B. To use the statical or common formulæ, the temperature of the column AC must be known; in applying these formulæ it is assumed that the mean temperature of this column is equal to the mean of the temperatures observed at A and B.

"How admissible this assumption is will appear at once when the manner in which the air acquires and loses heat is recalled. The body of the atmosphere is heated directly by the sun and gives off its heat by radiation into space. The surface of the earth is heated and cooled in the same manner, but many times more rapidly, so that by day it is always much warmer than the body of the air, and by night it is much cooler. A layer of air next to the earth receives its warmth from the earth, and is thereby caused to differ widely in temperature from the remainder of the atmosphere. Not only is the greater part of the column inaccessible to us, but that portion

* Williamson, page 68.

to which our observations are restricted is the portion least representative of all."*

By measuring the difference of elevation of two points with the spirit level, reversing the barometer formula, and computing the temperature of the air column, it has been found that in middle latitudes the average daily range of the temperature of the body of the air is about 4° of the superficial layer is from 10° to 20° near the sea-shore, and from 20° to 35° in the interior of continents. There is a stratum of air near the surface (Fig. 3) which oscillates daily through this wide range, while the temperature of the upper and larger portion of the column AC is relatively constant. Therefore the mean of the observed temperatures absolutely fails to give the mean temperature of the column AC as required by the formula.

§ 35. Nor does the trouble end here. "Whenever the ground layer is cooler than the air above, it is of course heavier, and, like any other heavy fluid, it flows down hill and accumulates in valleys, forming lakes of cold air. The nightly layer of abnormally cool air is therefore thinner on eminences than in valleys, and the contrast increases as the night advances. When the conditions are reversed so that the ground layer is warmer than the air above it, it has a tendency to rise, but accomplishes the change in an irregular manner, breaking through the immediately superior layer here and there and rising in streams which spread out in sheets wherever the conditions of equilibrium are reached." Observers in balloons, as they ascend or descend, rarely find an orderly succession of temperatures. If, therefore, we could in some way determine the temperature of some point in the upper portion of the column AC, we should still be unable to deduce the mean temperature of the column with a high degree of accuracy."

§ 36. *Humidity.*—The errors in barometric leveling due to the moisture in the air are essentially the same in kind as those due to the uncertainty of the temperature. The observations are made in the stratum next to the earth in which the amount of moisture is the greatest and the most variable. A change of station of a few feet, or a slight variation in the direction or force of the wind, will often cause a very important difference in the amount of watery vapor. The variations in moisture of the different portions of the atmosphere are greater than the variations in temperature. The diffusion of aqueous vapor is so slow that its effect may be neglected, and the distribution considered as taking place only by the circulation of the air. For this reason, then, there will be the same heterogeneity of moisture as of temperature, which has already been discussed.

"The variations in the hygrometric state are still further increased by the laws of condensation. At the surface of the earth there is an almost continuous passage of moisture from ground to air, only a part of the total exhalation being returned as dew. The daily circulation incited by the heat of the sun carries the moistened air upward and eventually the water is returned to the earth in the form of rain or snow, but the condensation and succeeding precipitation are exceedingly irregular. Whenever, therefore, a current of air moves upward and its temperature is lowered by rarefaction, a point may be reached where the accompanying vapor can no longer exist as such, and is condensed to cloud or even to rain or snow. On the other hand, whenever a current of air moves downward, its capacity for moisture is increased, and it acquires a quasi-absorbent power, so as to take up water from whatever moist surface it touches."

The irregularities of humidity are greater proportionally than the associated irregularities of temperature, but the error in the difference of altitude due to humidity is less than that due to temperature, because humidity is a much smaller factor of hypsometric problems.

### Dynamical Formulas.

§ 37. *Ferrel's Formula.*—Ferrel* has deduced from a consideration of dynamical principles, a barometric formula which distinctly recognizes the defects, as discussed above, of formulæ founded upon a statical condition of the atmosphere, and which indicates a method of

* Gilbert in U. S. G. S. Report.

* U. S. C. S. Report, 1881, pp. 225-68.

remedying them. Although the formula is very carefully and ingeniously worked out, yet it is probably of little use for ordinary hypsometrical work, since it requires observations to be made for a long time over a considerable area, to get the data by which to compute corrections for gradient, temperature, and humidity.

Without the data for making these reductions, this formula is essentially the same and has essentially the same defects as the formulæ depending upon a statical condition of the atmosphere. *

§ 38 *Gilbert's Formula.*—Gilbert † has developed a method for determining heights with the barometer which does not require observations of the temperature and humidity of the air. His method requires simultaneous observations of the barometer at three stations, the vertical distance between two of which is known; from the known difference between two of the stations and the observations at each, the actual density of the air can be found; then the true density can be used to compute the difference of elevation between either of these stations and the third.

The method is most accurate when the three stations are in the same vertical and when the one whose elevation is desired lies between the two, the difference of whose elevations is known; the method is applicable, but is less accurate, when the stations are not in the same vertical, or when the one whose height is sought lies either above or below the other two.

"One of the distinctive characteristics of this method is that it observes density directly, whereas other methods observe temperature and moisture only and deduce density. The only reason which has ever existed for measuring the temperature of the air and the moisture in it has been to ascertain its density. A second distinctive feature is that this method employs in its determination of density a column of air comparable in height with the one to be measured and fairly representative of it, while other methods base their diagnosis of the column to be meas ured on density determinations made close to the ground, where, as a rule, the conditions are not representative." It will be shown presently that this method also has serious defects.

§ 39. The formula for this method is deduced as follows:

Let L, N and U represent the altitudes of the lower, new and upper stations respectively; let $l$, $n$ and $u$ represent the synchronous barometric readings at these same stations corrected for temperature of the instrument and instrumental errors. Let B = the vertical base line, or the known difference of altitude of the upper and lower stations, B = U − L. Let A = the required difference of altitude N − L, and let $a$ = an approximate value of A.

Since B = U − L,
and A = N − L, B − A = U − N.

For convenience refer all vertical distances to the lower station as an origin.

If for the present we neglect the decrease in temperature and moisture with an increase of the altitude, and assume that the accidental or temporary variations of density due to temperature and humidity are the same in both columns, the following proportion may be made:

The approximate height of the base line : the true height of the base line, B,
∴ the approximate height of the new station : the true h'ght of the new station, A.

The approximate height (length) of the base line, as deduced from the readings of the barometer at the two stations is, C (log. $l$ − log. $n$) in which C is the barometer constant. In the same way the approximate height of the new station above the lower is C (log. $l$ − log. $u$). Substituting these values, the above proportion becomes,

C (log. $l$ − log. $u$) : B ∴
C (log. $l$ − log. $n$) : A.

or $a = \mathrm{B}\dfrac{\log.\ l - \log.\ n}{\log.\ l - \log.\ u}$ (15), in which $a$ is written instead of A, owing to the neglect of the variation of temperature and humidity with the altitude.

§ 40. The preceding equation would give the correct result if the atmospheric column were uniform in temperature, and if its aqueous vapor were uniformly distributed; but since this is never the case there must be added a term which

* Wm. Ferrel in U. S. C & G. S R., 1881, p. 243.
† In U. S. Geol. S. Report, 1880-1.

shall take account of the variation of temperature and moisture with the altitude.

It is well known that in a general way the temperature and moisture decrease with the altitude; but the exact law of this variation has not yet been discovered. Therefore, before the correction to be added to equation (15) can be determined, it will be necessary to assume some law for this variation.

"If the air were of uniform density, and the element of temperature were introduced alone, the high temperatures at low altitudes would cause a dilation there, and the low temperatures at high altitudes would cause a contraction, and the resulting distribution of densities would be characterized by an increase from below upward. If the air were of uniform density and the element of vapor distribution were introduced alone, the greater per cent. of aqueous vapor (which is a rarer gas than dry air) in the lower strata, would cause them to be relatively rare, and the resulting distribution of densities would be characterized by an increase from below upwards."* Consequently Gilbert* assumes that the increase in density due to temperature and humidity varies directly as the altitude. This may not be the true law, and whenever a better assumption becomes possible it should be introduced instead of the one here used.

In Sec. 3 tests of the complete formula will be given, which will afford an idea of the admissibility of this assumption.

§ 41. To embody this correction in the formula, let D represent the vertical distance in which the increase of density due to temperature and humidity is equal to the density at the ground; then the increase of density for each unit of vertical space is expressed by $\frac{1}{D}$. The mean density of the volume of air between the upper and lower station, in so far as it depends upon temperature and humidity, occurs at its middle point, which is a distance $\frac{B}{2}$ above the lower station. Likewise the mean density of the column between the lower and the new station is at a point $\frac{A}{2}$ above the lower. The vertical distance between these points is $\frac{B}{2}-\frac{A}{2}$. The decrease of density from the middle point of the column A to the middle point of the column B is $\frac{B-A}{2}\cdot\frac{1}{D}$; that is, the mean density of the column A is $\frac{B-A}{2D}$ greater than that of the column B.

In deducing the first term (15) of the proposed formula, it was assumed that the density as far as it depended upon temperature and humidity was uniform throughout both columns; but we have just shown that the element of the density varies directly as the altitude; consequently a term must be added to (15) to correct for the variation. It has just been shown that the mean density of A is $\frac{B-A}{2D}$ greater than that of B. The mean density of B is the unit or standard density; consequently, to express the density of A in terms of B, the density of A, as assumed in (15), must be diminished by $\frac{B-A}{2D}$ A.

Finally, the neglect of the variation of density with temperature and humidity assume too great a density for column A, and since heights are universally proportional to densities, that which makes the density too great makes the height too small; therefore the height of A as deduced from (15) must be increased by the quantity $\frac{B-A}{2D}$ A.

Adding this term to (15) gives for the height A of the new station,

$$A=B\frac{\log.\ l-\log.\ n}{\log.\ l-\log.\ u}+A\frac{(B-A)}{2D} \qquad (16)$$

Since the last term is always small, $a$ can be substituted for A, thereby making the formula more convenient to compute.

§ 42. If the position of the new station be referred to the upper station instead of the lower, the above formula will remain unchanged, except $l$ and $n$, and $l$ and $u$ will change places.

The formula is applicable, even though the new station is not intermediate in height between the other two; if the new station is above both the others, the quantity (B−A) then becomes minus,

* U. S. Geological Survey Report, 1881, p. 441.

and the last term is subtracted; if the new station is below both the other two, the numerators of both fractions will be minus, and the result will be the sum of the two terms.*

§ 43. The quantity D can be found only by experiment; to find it, observe the barometer at all three stations, determine A and B by a spirit level and compute D. The experiments should cover a great range of conditions so as to secure a fair mean value. Unfortunately D has not yet been determined from sufficiently varied conditions. The only value known is one determined by Gilbert from observations at only two sets of stations, and one of them was not very satisfactory. In this way it was found that D=245.000 feet.

The internal evidence of the observations from which this value is derived is such that it is probable "its real value will eventually be found to be somewhat smaller than the one provisionally assigned." †

Happily, the last term is always relatively small, and hence any uncertainty in the value of D will have only a small effect upon the final result. The uncertainty in the value of D is the chief defect in this formula. Introducing this value of D, (16) becomes

$$A(\text{in feet}) = B\frac{\log.l - \log.n}{\log.l - \log.u} + \frac{A(B-A)}{490{,}000} \quad (17)$$

$$A(\text{in meters}) = B\frac{\log.l - \log.n}{\log.l - \log.u} + \frac{A(B-A)}{149{,}349} \quad (18)$$

§ 44. *Reduction Tables.*—The use of all the preceding formulæ is very much simplified by tables which facilitate their application. Guyot's collection (Smithsonian Miscellaneous Collection, Vol. 1), contains tables for the application of all the principal statical formulæ. The appendix of Williamson *On the Use of the Barometer* contains a series of tables for La Place's form of Plantamour's formula (§ 22), with Regnault's coefficient. The same tables are also given in Lee's Tables. pp. 148–182. The U. S. Geological Survey Report for 1881 contains the only table necessary in applying Gilbert's formula.

Tables are useful where a great number of observations are to be reduced; but they generally contain an unnecessary number of figures, and hold forth a show of extreme accuracy which the nature of the observations themselves cannot justify.

§ 45. In the succeeding section it will be shown that statical formulæ are generally applied in such a way as to largely eliminate the defects referred to in this section. It is impossible to completely eliminate the errors due to gradient, temperature, etc., and, consequently, difference of elevation cannot be determined with precision by means of the barometer.

## Section 3.

### THE PRACTICE.

§ 46. *Common Method.*—Results may be obtained by using only one barometer, which is carried from station to station, one or more observations being made a each station; but results obtained in such a manner would be only rude approximations, owing to errors of gradient. The greater the distance between the two points the greater the error. Distant stations are sometimes connected by intermediate ones.

The errors due to gradient are partially eliminated by making simultaneous observations at the two stations. If the phase and the amplitude of the variation were the same at both stations, which probably seldom or never occurs, simultaneous observations would give results independent of this class of errors. Errors due to gradient are still further reduced by making a number of simultaneous observations and using the mean; this eliminates only the variable element and fails to take account of permanent gradient.

It is often recommended that the observations be made at certain hours of the day, at which time it is supposed the diurnal and annual gradients are zero. These times can only be determined from experiment, and will vary with the state of the atmosphere, the season, the locality, the elevation, etc. The U. S. Coast Survey* recommend the following times, subject to the preceding limitations. They were probably deduced for the middle Atlantic coast.

The hours refer to the middle of the

* Gilbert, page 442.
† Gilbert, p. 502.

* Report, 1876, p. 349.

month, other times are to be determined by interpolation:

| | | | | | |
|---|---|---|---|---|---|
| January | | | | 1 | P.M. |
| February | 10 | A.M. | and | 4 | " |
| March | 8 | " | " | 6 | " |
| April | 7 30 | " | " | 7 | " |
| May | 7 | " | " | 7 | " |
| June | 6.30 | " | " | 9.30 | " |
| July | 6.30 | " | " | 9.30 | " |
| August | 7 | " | " | 7.30 | " |
| September | 8 | " | " | 6 | " |
| October | 10 | " | " | 3.30 | " |
| November | 10.30 | " | " | 2.30 | " |
| December | at no time. | | | | |

§ 47. Observations made by the preceding method must be reduced by some of the statical formulæ. Notice that the preceding methods do not eliminate the error due to the fact that the mean of the observed temperatures does not represent the mean temperature of the air column.

§ 48. *Williamson's Method of Eliminating Gradient Errors.**—This method is specially adapted to reconnoissances and topographical surveys. A centrally located station, called a base station, is chosen, at which the barometer is read at stated hours each day for several days. In the meantime, itinerary observers make observations at the various points, the elevations of which are to be determined, and take pains to have their observations correspond in time with one of the observations at the base station. In the progress of the itinerary survey, a series of observations, similar to those at the base station, are made as frequently as practicable at semi-permanent camps; the object of both series being to ascertain the nature of the diurnal variation of pressure and temperature.

The barometric readings at the base stations, corrected for temperature of the instruments, are plotted upon ruled paper so as to exhibit their curve, and all readings shown by inspection to be influenced by abrupt and violent atmospheric disturbances, such as thunder-storms, are discarded, their places being filled by interpolations. From the corrected observations at the base stations, a correction is deduced, which, being applied to the several barometric readings, reduce them to the daily mean; applying this correction eliminates at least part of the effect of diurnal gradient.

Instead of determining the temperature of the air column from the temperature at the time of observing, the mean temperature of the day is used; this can be quite accurately determined at the base stations, but is only approximately known at the other stations. Notice that the mean of the daily means will not be the mean temperature of the vertical air column.

The difference of altitude can then be computed from the reduced barometric readings and the mean daily temperature, by using any of the statical formulæ; Williamson himself used his translation of Plantamour's formula (§ 22).

§ 49. *Whitney's Method.*—"From observations made in connection with the Geological Survey of California, a series of corrections were deduced for reducing the barometric readings made at different hours of the day, of the different days of the the different months, and for the different altitudes to the daily mean for the year. These corrections can only be used in the neighborhood in which the observations on which they were based were made. Similar tables made for different climates would differ materially from each other." For tables constructed upon this principle for the climates of Germany, Philadelphia and Greenwich respectively, see Guyot's Collection, Group D., 3d Ed., pp. 80–1, 93 and 94.

§ 50. *Plantamour's Method.*—In the hypsometric survey of Switzerland, Plantamour made simultaneous observations of the barometer, thermometer and psychrometer at Geneva, St. Bernard, and at the station, whose height was to be determined. The approximate difference of altitude between the new station and Geneva, and between it and St. Bernard, were computed by Plantamour's formula (§ 22); the difference of elevation between Geneva and St. Bernard was also computed. The computed difference of elevation between Geneva and St. Bernard computed with the actual difference of altitude, as determined by the spirit level, gave a correction to be applied to the computed differences for the new stations. The ingenious details of the computation are too complex to be described here.

* Williamson on the Barometer.

Marshall* and Rühlmann applied methods somewhat similar to the above.

§ 51. *Gilbert's Method.*—This method, which has already incidentally been fully described, is somewhat similar to the above, but differs from them in determining the height of the new station by the sole means of the observed pressures. A comparison between it and the several other methods seems to prove that it is the most accurate. †

§ 52. Unfortunately all methods of eliminating gradients involve considerable time and expense, and even then do not thoroughly accomplish the desired end, all of which shows that when great accuracy is desired the barometer should be dispensed with altogether, and the difference of elevation determined by some other means.

§ 53. *Sources of Error.*—The principal sources of error, as well as the means of eliminating them, have already incidentally been discussed, and need only to be referred to here.

1. *Instrumental Errors*, such as index error, imperfection of the scale, imperfect adjustment for capillarity of the tube, impure mercury, and errors in the attached thermometer.

The first is usually eliminated by an adjustment of the zero of the scale, and with a good instrument the others would be inappreciable.

2. *Errors of Observation*, as inaccuracy of making contact between the ivory point and the mercury, inaccuracy of the reading itself, and the inaccuracy in determining the temperature of the barometer. Gilbert ‡ from a comparison of 360 pairs of observations made by the Signal Service and the Geological Survey found the average error of observation to be a trifle less than three-thousandths of an inch. This difference does not involve the personal error between two observers, which, for even expert observers, may be nearly as much more. §

3. *Errors due to Gradient*, diurnal, annual, and abnormal, and those due to temperature and humidity. The errors of this class may have almost any value; the various methods of partially eliminating them have already been discussed.

4. *Errors due to the Effect of the Wind.* The wind may cause either a condensation or rarefaction of the air in the room in which the barometer is, or even in the cistern of the barometer itself. This effect will vary with the velocity of the wind, with the position of the openings with reference to the wind, etc. On Mount Washington, a wind of 50 miles per hour caused the barometer to read .13 of an inch too low. Its effect will vary as the square of the velocity. It may be nearly, if not wholly eliminated by having two apertures, one each on the windward and leeward side of the enclosed space.*

A similar effect of the wind is caused when the instrument is read in the immediate vicinity of any body which obstructs the wind. For example, if the barometer is observed on the windward side of a mountain, the reading will be too high; if on the leeward, too low. The only way to avoid this difficulty is in the selection of the stations; but it is not always possible so to avoid it.

§ 54. *Limits of Precision.*—It is sometimes stated that "the barometer is the most accurate instrument for determining differences of level." It needs only a moment's reflection to see that this cannot be true. The following results, given by Professor Guyot, are frequently quoted as showing the great accuracy of barometric instruments:

Mont Blanc, by barometer, 15,781 feet,
by spirit level, 15,780 feet.
Mount Washington, by barometer, 6,291.7 feet,
by spirit level, 6,293 feet.
In North Carolina, by barometer, 6,701 feet.
by spirit level, 6,711 feet.
In North Carolina, by barometer, 5,248 feet.
by spirit level, 5,246 feet.

These results are to be considered exceptional, and only obtained by numerous repetitions in various states of the atmosphere.

The difference of altitude computed from one or even several days' observations cannot be relied upon as being more than a rough approximation. This has been shown by Williamson, † who has computed the difference of altitude between Geneva and St. Bernard (using the same formula as in the last three examples quoted above) for every day for two years from daily simultaneous obser-

* Wheeler's Geological Survey, Vol. II., p. 522.
† Gilbert's U. S. G. S. R., 1881.
‡ Report U. S Geolog. Survey, 1880-1, p. 542.
§ U. S. C. S. Report, 1870, p. 79.

* Gilbert U. S. Geolog. Survey, 1880-1, p. 562.
† Williamson on the Barometer, p. 206.

vations. The difference between the result by the barometer and the spirit level, in several cases, was more than 3 per cent. Under less favorable circumstances the errors were even more than twice as great. *

The altitude computed by the monthly mean of daily observation for different months of the same year, and also for the same month of different years, differ as much as 1 per cent. †

§ 55. The following differences between the results by the barometer and the spirit level, do not indicate that high degree of accuracy in barometric hypsometry, even where a long series of observations is used, which was formerly supposed to be attainable by this means. The results by the barometer were obtained by computing the difference of altitude from monthly means of the mean of the daily observations, and taking the mean for the time stated. ‡

Sacramento and Summit,
3 years observations, −24 ft. in 6,989 ft.
Geneva and St. Bernard,
12 years observations, −2.6 met. in 2,070 met.
Portland and Mt. Washington,
6 years observations, +37 ft. in 6,289 ft.
Vera Cruz and City of Mexico,
1 years observations +5 met. in 2,282 met.

§ 56. For an interesting comparison of the absolute, and also the relative, errors of the various methods, see Gilbert's Memoirs, Chapt. III, in U. S. Geological Report, 1880–1.

For additional data concerning the accuracy of barometric leveling, see U. S. C. & G. Survey Report, 1870 p. 88; Do, 1871, p. 154–75; Do, 1876, p. 355–76.

§ 57. Although the barometer cannot be regarded as a hypsometric instrument of great precision, yet with care it can be made to give results with sufficient accuracy for reconnoissance or exploration. For this purpose, it is unexcelled by any other instrument, but this is about the only use of the instrument to the engineering profession.

* See also Gilbert, p 456-9.
† Williamson on Barometer, p. 236.
‡ U. S. C. S., 1881, p. 254.

## ELECTRIC RAILWAYS.

From "Industries."

The proposal to use electricity as a source of energy for working railways is very old. With whom it first originated will perhaps never be known, but it is probable that Professor Henry's "electric engine," which was invented in 1833, and especially Jacobi's famous experiment in 1839, which showed to the world that electricity could be used to propel a boat, directed public attention for the first time to the question of electric locomotion. This seems the more likely, as the first patent for an "electric railway" dates from 1840, and was granted by the United States Government to Henry Pinkus, who seems, however, not to have developed his invention. We hear nothing more about electric railways until the year 1845, when Professor Page invented a new electromotor, by the aid of which he actually succeeded, six years later, in working trains between Washington and Bladensburg, over a line of five miles in length. The speed was only 19 miles an hour, and the undertaking was commercially a failure, owing to the great cost of producing the electric current which worked the motor.

For the time being the subject dropped out of sight, and has only been revived during the last few years. This revival is in a great measure due to M. Fontaine's discovery—made at the the International Exhibition in Vienna, in 1873—that, by the aid of two dynamo machines and connecting cables, motive power could be transmitted over a considerable distance. Whether this discovery was purely accidental, or whether it was the legitimate and logical result of scientific investigation, is to this day a moot point; but whatever be its history, the practical effect was that henceforth the transmission of power, not only between two fixed dynamo machines, but also between a fixed dynamo machine and a train in motion, has become possible. The actual development of electric railways has, however, only taken place within the last five or six years, and now there are both in

Europe and in America many lines worked by electricity.

There are two ways in which an electric railway can be worked. We may either utilize the ordinary rolling stock, and replace the steam locomotive by an electric locomotive, or we may provide each passenger coach and each goods wagon with its own small electromotor, so that each vehicle becomes its own locomotive. In the latter case, the power is applied to each axle in the train, and the whole of its weight is utilized in producing adhesion. Of the difficulties connected with the conveyance of current to the train, and of those which at present stand in the way of an economical and certain method of regulating the speed, we shall speak presently. But, supposing that these difficulties can be overcome, it will be admitted that electric traction, especially when carried out on the latter plan, has many advantages over steam traction.

By making every wheel in the train a driver, the acceleration at which the train can start is greatly increased. There would be no difficulty in obtaining a speed of 30 miles an hour within 10 seconds from the moment of starting, and the strain due to inertia would not be greater, nor the sensation to passengers more disagreeable, than is the case now, when trains are stopped quickly by the application of powerful continuous brakes. In all probability strain and sensation would be less, because no jarring, as with a brake, would take place. This is a point of great importance for metropolitan railways, where trains succeed each other every few minutes, and where the time wasted to get up speed at every start is a considerable item in the total time required for the journey. On underground lines, the absence of smoke would also be an enormous advantage, resulting in a large increase of passenger traffic. We may here at once remark that the difficulties connected with the conveyance of electricity to the trains are the greater, the longer the line and the fewer the trains which run over it per day. On a short circular line like the Metropolitan Railway, the amount of traffic is so great, that it would pay to place the engine and dynamo almost at every station, and thus reduce the distance through which the current has to travel before it reaches the train, to a few hundred yards. By providing each coach with power, trains can be made up of as small a number of coaches as convenient, and thus a frequent service of short trains can be substituted for the present service of heavy trains at longer intervals —a decided advantage from the passenger's point of view. Another very important advantage is that of almost perfect safety. The late Professor Fleeming Jenkin, when working out the details of his Telpher Line, devised, with the assistance of Professors Ayrton and Perry, an automatic electrical block system, which is intended to prevent one train from overtaking another. As soon as a train enters on a section which has not yet been cleared by the preceding train, the current is automatically withdrawn from the electromotor of the second train, and thus the latter stops for want of propelling power. The first train, in clearing the section, restores the current to the second train, and thus allows it to proceed. Some such arrangement could, no doubt, be adopted on electric railways intended for passenger traffic, and, if added to the ordinary block system, would render collisions almost impossible. Since electromotors contain no parts having a reciprocating motion, such as the piston and connecting-rod of a steam engine, they can run at any speed without oscillation. There is, consequently, nothing to limit the speed of an electrically-propelled car but the tensile strength of the wheel tire, which, under the action of centrifugal force, might burst if its circumferential speed exceed a certain limit. We may mention here, in parenthesis, what is doubtless known to our engineering readers, viz., that this limiting speed does in no way depend on the diameter of the wheel, but simply on the tensile strength and specific gravity of the metal. For good steel, the safe limiting speed is considerably over 100 miles an hour, and it is therefore by no means impossible that about double the present speed of traveling might be obtained in future on electric railways. Speaking on this point at the Society of Arts in 1883, Professor Forbes said that he hoped to live to see the day when he could travel from London to Edinburgh in 3½ hours.

With these remarks we have not yet

exhausted the list of advantages possessed by electrically-propelled coaches over the usual system of trains drawn by steam locomotives. The permanent way, bridges, and viaducts may be built altogether lighter, steeper gradients and sharper curves may be used, and the wear and tear of the road must necessarily be less with light, smooth running electromotors, than with a 40 ton engine pounding along. Now, it might be asked—How is it that, with all these advantages in favor of electric traction, our railways, and, indeed, those of the whole world, are still worked on the train system by steam locomotives? The answer to this question is, that up to the present no satisfactory solution has been found for the three great difficulties which stand in the way of applying electricity to railway purposes.

These are, first, the difficulty of conveying the electric energy to the train; secondly, the weight and high speed of electromotors as at present constructed; and, thirdly, the want of some contrivance by which the speed and power of electromotors could be varied in a simple and economical way.

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## REPORT OF THE INTERNATIONAL COMMISSION ON THE SUEZ CANAL.

By A. FLAMANT.

Translated from Annales des Ponts et Chaussées, for Abstracts of the Institution of Civil Engineers.

The Commission was appointed in 1884, to determine what new measures, in respect of works and navigation, should be undertaken to enable the ship-canal to meet fully the exigencies of a traffic exceeding 10,000,000 tons per annum. Its Report was presented in February, 1885, of which document the author furnishes a summary. The Commission considered three methods of increasing the carrying capacity of the canal, namely: (1) widening the existing canal; (2) construction of a second canal; (3) doubling the capacity of the canal by a combination of the first two methods. When the canal was first designed, in 1856, it was supposed that two vessels, being towed, could easily pass where the bottom width was 144 feet, or double the normal width adopted. At the present day, however, when vessels of 50 feet in width propel themselves through the canal, a bottom width of 230 feet has been proposed for the 81 miles from Port Said to the southern end of the Bitter Lakes, where the tidal currents do not exceed 1 knot an hour, and 262 feet for the rest of the distance to Suez, where the currents often exceed two knots, in order that the vessels may pass each other freely. The cost of this widening was estimated at £8,240,000, supposing the depth of the canal remained as at present, 26¼ feet below low-water of ordinary spring tides, but would be increased by £975,200 if the depth was augmented to 29½ feet, unless the proposed width could be reduced 18 feet. The construction of a second canal, within the limits of the company's lands, having, like the existing canal, a bottom width of 72 feet, widened out to 131 feet through the small Bitter Lakes, was estimated at from £8,200,000 to £8,920,000, with an additional cost of £698,800 if made 29½ feet deep. The third plan took into consideration the different velocities of the tidal currents north and south of the Bitter Lakes. Assuming that the greater velocity might lead to collisions between vessels passing on a single enlarged canal, it would be advisable to restrict the enlargement to the northern portion, and to form a second canal between the Bitter Lakes and Suez.

The Commission decided unanimously in favor of the enlargement of the existing canal from the Mediterranean to the Red Sea, for the following reasons. An enlarged section would enable vessels to increase their speed from 5⅓ to 8 knots an hour, and thus to traverse the canal in about twelve hours, which could never be accomplished with two separate canals; and, moreover, there would be only two banks to maintain, instead of four. This increase of speed will greatly facilitate the steering, which, together with the

greater width of canal, will enable vessels to avoid stranding on the banks, an important gain which would not be obtained with two canals. The danger of collisions between passing vessels on a single canal will be obviated by the great increase in width proposed for the canal, and by reducing the speed of the vessels in the act of passing. Moreover, the plan of enlargement will include the easing of the curves on the canal, and will thus remove the impediments which these sharp and narrow bends present to vessels of 360 feet in length, which is quite an ordinary length now, though rare twenty years ago. Lastly, this system will possess the inestimable advantage of enabling each successive portion of enlargement to be at once utilized as an addition to the passing places for vessels.

The Commission exhibited some difference of opinion on the question whether, in order to keep within the lower estimate, the depth should be increased at the expense of the width; but it was eventually agreed that the depth should be increased to twenty-eight feet, with a corresponding decrease in the proposed width of the northern portion to 213 feet, and of the southern portion to 246 feet, measured at a depth of 26¼ feet. The present limit of draught is 24½ feet; but it was considered necessary to provide for a probable increase to a maximum of 27 feet, which a depth of 28 feet would just accomplish, leaving the deepening to 29½ feet for a future time, when the increased number of vessels of large draught may demand it. Whilst adopting the above width for the straight portions of the canal, as sanctioned by the experience of navigation on the Clyde, the Tyne, the South Pass of the Mississippi, and the Sulina mouth of the Danube, with similar widths and more rapid currents, the Commission laid down the widths suitable at curves in proportion to their radii. In the northern portion of the canal the widths, 26¼ feet below low water, were fixed at 246 feet for curves exceeding 8,200 feet in radius, and 262 feet for sharper curves; whilst for the southern portion, the widths at the curves, which all exceed 8,200 feet in radius, were designed to be 262 feet. As the long slopes of the canal banks, where unprotected by vegetation, are seriously damaged by the wash of passing vessels, the formation of a narrow berme on each slope, below the action of the waves, about 6½ feet below the water surface, has been recommended, and also the protection of the slopes from that depth up to 3¼ feet above the water by pitching. Owing to the increased speed admissible on the enlarged canal, the normal period of transit will not exceed twelve and a half hours, allowing ample margin for stoppages; so that the journey might be accomplished in a single day, if an early start was effected, so as not to be overtaken by nightfall; whereas at present the average time occupied in passing through the canal is forty hours. The Commission considers that the works should be executed in three different stages, namely: (1) An adequate increase in width, to provide for the passing of vessels at any point of the canal, by stopping one vessel and drawing it to the side, together with an increase in depth to 28 feet, at an estimated cost of £2,449,750; (2) the completion of the enlargement to the full width prescribed, at a cost of £5,190,900; (3) the deepening of the canal throughout to a depth of 29½ feet, at a cost of £618,050, making a total estimated cost of £8,258,700 for the whole of the works. Adding, however, £40,000 for sundry expenses, and deducting £180,100 for sale of plant, the final estimate is £8,118,600.

## REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—The last number of the *Transactions* contains address of President Henry, read at the Denver convention; a paper on the strength of columns, with some new formulæ by Thomas H. Johnson; a new formula for compression members by R. Krohn.

## ENGINEERING NOTES.

Steel Wire for Bridges.—A paper was read by Dr. Percy, F. R. S, at the annual meeting of the Iron and Steel Institute on "Steel Wire of High Tenacity." The writer said that in the address which he delivered to the Iron and Steel Institute in May, 1885, he mentioned steel wire of high tenacity, or, in other words, of great tensile strength, amounting to not less than 120 tons per square inch of transverse sectional area, and he also then said that he had recently seen it stated that mild steel in the form of rod or bar had been produced of equal tensile strength. But as no authoritative evidence was given of the truth of the statement, he determined to search for trust-

worthy information on the subject, and he had now the pleasure of communicating to the Institute the results which he had obtained. In October last he visited the highly-interesting and extensive plough works of John Fowler & Co., at Leeds. His attention was particularly attracted to their steel-wire ropes, for the excellence of which they had justly acquired a high and world-wide reputation. He inquired concerning the tensile strength of the wire which was used for the purpose, and he was astonished to find that it amounted to 150 tons or more. At his request, Sir Frederick Abel, chemist to the War Department, ascertained its chemical composition, and Colonel Maitland, R. A., superintendent of the gun factories at the Woolwich Arsenal, ascertained its tensile strength. Colonel Maitland, in his report, said the steel wire was hard and extraordinarily tough, and so rigid that even with the aid of pillars it required the exercise of considerable force to bend it. It broke when bent on itself, and the fractured surface was ragged, without showing any appearance of grain. The specific gravity of the wire at 60 deg. Fahr. in its original state—that was before Colonel Maitland began to operate upon it—was 7·8142, and after rupture 7·8082. The same weight of wire was used in both these determinations, but as it amounted to only about eight grammes, Mr. Deering suggested that the difference between the two specific gravities might not be greater than the probable error of experiment. It was, however, a difference in the direction which might have been anticipated. The specific gravity of the wire was increased by annealing from 7·8082 to 7·8402—a difference also in the direction to be expected, though Mr. Deering again suggested that it might be within the limits of possible error. The tensile strength of the wire was determined with great care and thoroughness. It broke under a load of 154 tons. The final elongation in the experiment immediately preceding rupture was, with load, 1·1 inch, and without load 0·75. The composition of the wire was as follows:—

| Total. | Per Cent. |
|---|---|
| Carbon | 0 828 |
| Manganese | 0·587 |
| Silicon | 0·143 |
| Sulphur | 0·009 |
| Copper | 0 030 |
| Phosphorus | Nil. |

The wire was carefully examined for chromium, titanium, and tungsen, but no trace of those metals was detected. The percentage of carbon was greatly in excess of what was present in mild steel. After experiments with thicker wires, it appeared that as the diameter increased the tensile strength of the wire notably decreased. The interesting question, Why was it that steel only when in the form of comparatively fine wire should be capable of acquiring such a high degree of tenacity? remained to be solved. Was it that during the process of wire drawing a more intimate interlocking, so to speak, of its particles might occur, which increased its resistance to the tearing asunder of those particles? That such resistance was enormously augmented was certain, but if it were due to the cause he had suggested another difficulty arose, for how, it might be asked, could a more intimate interlocking of its particles be reconciled with the fact that its specific gravity, so far from being increased, as in that case might be reasonably anticipated, actually decreased, or what was equitable, its volume was augmented?

In the discussion which followed, the speakers could not account for the greater tenacity of fine wire, and, although the President was asked for some further explanation, he admitted that he could give no solution of the problem.

Colonel Maitland said the reason he was asked to make the experiments was because the War Office were making guns lined with wire. The wire used was from 90 to 110 tons breaking strain. It was a quarter of an inch in diameter, and a sixteenth of an inch in thickness. The experiments showed that wire might be used of higher tensile strength, but he did not know that that would be of much advantage in gun-making.

Mr. Bateson was of opinion that larger wires might be made to stand equal strain to that of the smaller wire, supposing that mechanical means were provided for doing it—*Architect.*

In a letter dated Carleste Bay, Babadoes, W. I., March 1, 1886, Commander A. S. Barker, commanding the Enterprise, writes as follows:—"I have the honor to transmit a report of deep sea soundings taken between Montevideo and Barbadoes. Seventy-two casts were taken, and the distance run was 5031 miles. In order to avoid the Challenger's track I steered northward towards Nelson shoal, where the chart shows nineteen feet. We found 2088 fathoms when over the spot, but there may be a shoal in the vicinity nevertheless. From this point I steamed slowly, running from about 200 to 250 miles to the northward of the Challenger's line, taking casts at intervals of about sixty miles, the average depth being about 2000 fathoms. In latitude 31 deg. 22 min., south, longitude 36 deg. 39 min. west, the water shoaled to 1469 fathoms, and the next cast, taken in latitude 31 deg 15 min. south, longitude 35 deg. 42 min west, was only 547 fathoms. From this position casts were taken at intervals of five miles or thereabouts until over the shoalest part of the bank. The least depth found by us was 378 fathoms in latitude 31 deg. 2 min. south, longitude 34 deg. 27 min. west. Of course it is impossible to state how much water there may be on the bank in the neighborhood of our casts. It is very doubtful if we crossed the shoalest part, as it extends for about 150 miles in longitude and how much in latitude is not known. If the vessels on the South Atlantic station were provided with deep sea sounding machines they could determine the extent of this bank with very little trouble. After leaving St. Thomas, W.I., we expended all the remaining shot we had on board taking deep sea soundings. The first cast was taken in latitude 19 deg. 53 min. north, longitude 65 deg 45 min. west, where we found 4529 fathoms—excellent cast. The

position of this cast is about 40 east-north-east of that where Lieutenant Commander Brownson found 4561 fathoms."

Brick Masonry in Design.—The endurance with which brick will withstand frost and fire, and the disintegrating forces of nature, in addition to its resistance to crushing and facility of construction, have constituted a very important reason for its value for building purposes: but its use for recent years had been mainly for plain brick in plain walls, whose monotony permitted no artistic effects, beyond a few geometrical devices of the most primitive features of ornament. Additions of cast iron serve as ornaments only in the phraseology of trade catalogues, and the mixture of stone with brick generally results in flaring contrasts, producing harsh dissonance in the design. The facades of such buildings show that this is brick, this is stone, and this is cast iron, but always fail to impress the beholder with the rich sense of a harmonious design. The use of the finer varieties of clay in terra cotta figures laid among the brick work, furnishes a field of architectural design hardly appreciated. The heavy masses of brick, divided by its regular lines of demarkation, serve as the honest element of utility which is fundametal to every design; while the introduction of the same material in terra cotta ornaments at suitable places, gives the most appropriate elements of beauty in the design, for the same material shows alike its capacity for utility and decoration. The absorption of light by clay, whether burned or merely dried, abates reflection and renders its shape more clearly visible than any substance used in building construction. The clay design of a statue embodies a sense of life, received from the hands of the designer; but the glaring plaster cast tells the secret of the embalming process. The present use of enameled brick and tiles afford a method of introducing chromatic effects into brickwork; but the utmost care and restraint is necessary, lest the effect result in a glaring innovation, rather than an artistic touch tending to relieve a monotony of color.—*London Engineering.*

## IRON AND STEEL NOTES.

Steel Versus Iron Girders.—A series of important tests have recently been made on Bessemer steel and iron girders by Messrs. De Bergue & Co., of Manchester. These tests, which have been made under the direction of Messrs. Barningham Brothers, of Manchester, on behalf of the Darlington Steel and Iron Company, have had for their special object the determining of the relative strength of steel and iron for structural purposes, and the general results obtained were, with equal sections, about 40 to 50 per cent. in favor of the steel as compared with the iron girders.

Effect of Overblowing Steel upon the Elimination of Phosphorus.—A. Tamm describes in the *Jernkontorets Annaler* a somewhat curious experiment made at the Vestanfoers Bessemer Works. A charge of 1,850 kilogrammes of pig-iron was blown until it was reduced to only 400 kilogrammes. The following analyses show the composition of the pig (A), the composition of the steel when the flame became short (B), its constituents an hour later (C), and the final product (D):—

| | A. Pig. | B. Flame. short. | C. One hour later. | D. Final Product. |
|---|---|---|---|---|
| Carbon..... | 4·05 | 0·03 | 0·025 | 0·02 |
| Silicon..... | 1·125 | 0·025 | 0·040 | 0·014 |
| Phosphorus.. . | 0·024 | 0·029 | 0.046 | 0·066 |
| Sulphur ..... | | Trace. | | |
| Manganese..... | 4·40 | 0 10 | 0·03 | 0 03 |

This proves that, even if overblowing is carried to an extreme, on an acid bottom, the phosphorus is not at all eliminated. The increase, of course, is due to concentration in a smaller quantity of metal.

Polishing the Interior of Metal Tubes.—Within the last twenty years the pneumatic system of transmitting packages has been brought to a practical success; but the tubes, which form one of the principal parts of the apparatus, are very expensive on account of the absence of expeditious means to produce the necessarily smooth and uniform interior required for this purpose. A machine has been invented and recently patented which presents a number of valuable features, and presents probably a complete solution of the problem of rapidly polishing the interior of long sections of iron or other metal tubing, so that the cost is not increased beyond a proper limit, and especially adapts them for the pneumatic system of transmission, to the exclusion of the expensive brass tubes that have usually been employed for that purpose. The machine, as we find it described, consists essentially of a strong iron bed of a trough shape, and of a length to suit the size and length of the pipes to be smoothed. At one end of the bed is attached mechanism for giving a rotary motion to a long bar which has secured to the outer end one or more cylinders of emery. The pipe is held by means of a sleeve which is carried along the bed-plate on a slide, by means of suitable feed mechanism, at the exact speed desired. The sleeve has a pulley attached to it which is slowly revolved by means of a belt in the opposite direction to that of the bar to which the emery cylinders are attached. In connection with the smoothing mechanism is a hose which is so arranged that its nozzle is carried along with the pipe to furnish water for clearing the bore of cuttings, &c., as the smoothing process proceeds. In operation, the bar, with the emery cylinders, is given a rapid speed, then introduced in the end of the pipe, when, being driven in the opposite direction at a slow speed and the interior being lubricated with water, the smoothing proceeds through the pipe at a fair rate, predetermined by the feed apparatus. When the pipe has reached the limit of its movement, the operator, by means of a lever, shifts the belts so that the movement of the feed is reversed and the sleeve and pipe are moved back to the place from which they started, when the pipe is removed and another placed in position to undergo the same operation. This machine is stated to be so perfectly adapted to the purpose that long pieces of pipe

are perfectly smoothed to a uniform diameter at a very rapid rate. The machine will accomplish its work with an operator of ordinary skill, and will greatly cheapen all kinds of tubing in which a smooth interior is required.—*Iron Age.*

## RAILWAY NOTES.

THE EUPHRATES VALLEY RAILWAY.—In the *London Times* recently Sir William Andrew has again made a fresh appeal on behalf of the Euphrates Valley Railway. Now that a Premier is in office who is avowedly a warm admirer of the scheme, we shall doubtless hear more about it before long, more especially as Russia's action at Batoum has revived public interest in Asia Minor. The engineering obstacles to the realization of the project are practically *nil*, and we imagine that the line could be constructed easily for the six millions sterling estimated by Sir William Andrew. All along the real impediments the supporters of the idea have had to encounter have been of a political character. On one occasion its success seemed assured, but at the last moment the late Emperor Napoleon intervened, and for the sake of the French alliance Lord Palmerston sacrificed the railway. Recently French rivalry in Asia Minor has died out, and the only opposition would proceed from Russia, who naturally would not approve of any railway abridging the distance between England and India. On the other hand an altogether new factor has been introduced into the matter by the astonishingly rapid extension of the Russian railway system to within hitting distance of our Indian confines. In the opinion of our ablest strategists, if Russia has a railway to India, England also ought to have a railway to India. Such a line would start from opposite Cyprus, and proceed along the Euphrates to the Persian Gulf—being at both ends under the control of our fleet. From the Persian Gulf it would extend along the Persian littoral to Belloochistan and India. It is sometimes said that in time of war Russia might cut it, but this begs the commercial aspect of the question. In the *Contemporary Review* this month Mr. Charles Marvin points out that if Russia penetrates unopposed to the Persian Gulf she will split the continents of Europe and Asia in halves, and dominate the whole of the land routes between east and west. If the construction of the Euphrates Valley Railway would tend to develop the region and prevent Protectionist Russia achieving this great design, surely a guarantee for the six millions would be well spent, in the interest of English commerce, without touching the military aspect at all.

THE heaviest passenger train traffic in Switzerland in 1884 was on the Bodeli Railway, where it was equal to 235 each way daily, while on another it was only 35½; the heaviest freight traffic was only equal to 103 tons each way daily, while the lightest was only 6 tons. The little Rigi Railway (mountain), earned £2938 per mile from passengers, receiving 21⅜c. per passenger per mile. The total earnings of the Rigi were £3223 per mile, while the highest on any ordinary railway were £2399. One ordinary railway collected an average freight rate of 11c. per ton per mile, the Rigi getting 4s 3d. per mile for taking a ton up or down the mountain. The cost of working the Rigi was £2160 per mile, leaving £1063.

A RUSSIAN Commission appointed to test rails and tires found: (1) Tires from soft steel are more brittle, liable to break, than hard steel ones. (2) Tires from soft steel wear much more rapidly than hard ones, and are not to be recommended. (3) Very hard steel is bad in use and requires frequent turning up. (4) The best tires contained more carbon and much less manganese than the less excellent, 0·5 per cent. against 0·37 per cent. for carbon, and 0·37 per cent. against 0·76 for manganese. The proportion of silicon to phosphorus is pretty constant in the best tires. The commission recommended changes in the imperial regulations for rail testing, looking to the retention of the bending and drop tests, the former only within the elastic limit, the latter to be tried both with chilled—reduced to freezing temperature—rails and warm ones, with a reduction of the height of fall and omission of a second drop. Each charge is to be tested for the above by taking one rail out and testing it in three pieces separately. In addition, tensile and chemical tests are to be made periodically during delivery, for which limiting figures are set for strength and amount of injurious element, silicon, manganese and sulphur. For tires the drop test is to be reduced and the tensile test retained.

M. HENRY MATHIEU, chief engineer of the Southern Railway of France, has found that the average yearly consumption of sleepers on 80 per cent. of all the French railways for the five years ending with 1882 had been 92 per kilometer, equal to 148 per mile of line, excluding yards and sidings. Returning to the subject recently, he finds in 1883 the average consumption rose to 170 per mile, and in 1884 144½ per mile, and the average for the two years 159 per mile. The *Railroad Gazette* says:—"French railroads are reported to have 1450 sleepers per kilometer, or 2332 per mile, which puts them 27 in. only from center to center, and the consumption for maintenance indicates an average life of from 13⅜ to 16½ years for sleepers. Most of the railways report the number of sleepers used of each kind of wood, from which it appears that in 1883, 69·7 per cent. of them all were of oak, 15·6 beech, 12·1 pine and fir, and 2.6 chestnut and other woods, but in 1884 the proportions were quite different—60 per cent. oak, 22.1 beech, 15.6 pine and fir, and 2.3 chestnut, &c. Of the total number of sleepers reported used, 24 per cent. were imported in 1883, and 20¾ per cent in 1884. M. Mathieu says that the life of sleepers is increased one-half on the average by preservative processes; that of all the antiseptics tried in France only creosote and sulphate of copper are still used, and the creosote is generally preferred. An oak sleeper costing 5½f. is preserved at a cost of about a franc. On the Southern Railway, where three-fourths of the sleepers used are of the pine that grows on the landes, the sleepers cost from

36c. to 38c. each, and are preserved with copperas for 14c. and with creosote for 19c. each. The Orleans Railroad uses the same kind of sleepers, preserved with creosote, for about one-sixth of the whole consumption. The Northern Railroad finds that the use of a tarred felt paper between the rail and the sleeper increased the life of the latter about two years."

## ORDNANCE AND NAVAL.

THE BRENNAN TORPEDO.—Some further experiments have been made at Sheerness, with the Brennan torpedo, the results being described as exceedingly satisfactory. The experiments were carried on in conjunction with the electric search light at the Garrison Point Fort, and the weapon was steered about the harbor in different directions at the will of the operator in the torpedo room at the fort, and was finally directed at a target moored about a mile up the Medway, the mark being rendered discernible by means of the electric light. The torpedo is kept under control and steered by means of a wire attached to the machinery in the fort. When the experiments at the fort have concluded, it is proposed to test the adaptability of the torpedo for use as part of armament of ships of war.

SUBMARINE MINING EXPERIMENTS.—Extensive submarine mining experiments were carried out near Portsmouth on September 14, with the view of testing the efficiency of the present system of firing mines, the system, owing to the weakness of the detonating charges, having broken down at the recent naval review. Two experiments were made. The first was with observation mines, which consisted of a line of six mines, each containing 500 lb. of gun cotton, so arranged as to blow up an enemy's ship should it have crossed the line. The mines were at the bed of the channel, covered with 10 fathoms of water, and connected by an electric tube in which was inserted at each mine a charge of fulminate of mercury. On a key being pressed, four out of six mines were exploded, and each sent up a huge volume of water 400 feet high. Gunboats were stationed 600 yards off, and after the first violent shock the sensation was as though the boats were bumping heavily on rocks. These mines were laid on a mud bottom, large quantities of which, together with tons of fish, were blown up with the water. The next experiment was with a line of 12 countermines, supposed to be laid over an enemy's mined channel, and these also each weighed 500 lb. and were 180 feet apart On the key being pressed, 11 out of the 12 mines exploded; but, owing to these being laid on a sandy bottom, the shock was no greater to the gunboats than in the first experiment. Tests were carried out on a point of land eight miles from Portsmouth, where the effect of the shock was not felt.

THE "RESISTANCE" TORPEDO EXPERIMENTS.—Under the direction of the officers of the Vernon Torpedo School a protracted series of torpedo experiments was commenced on September 21 at Portsmouth, and will be continued until the Resistance, armor-clad man-of-war, which serves as the target, is blown up. The trial consisted in discharging 60 lb. of gun cotton at a distance of 10 yards from the ship, which is moored in such hollow water that, should she be sunk, she could be approached at low tide. At the trial the vessel was violently shaken by the concussion, but was not otherwise damaged, although it was clear that a much heavier charge would have done a good deal of mischief. The experiments were continued on September 22, and they constituted the first instance of a live Whitehead torpedo having been exploded against the hull of a ship. Hitherto their destructive effects have been a matter of assumption, and the present experiments are calculated to settle many practical questions connected with torpedo attack and defense which demanded a solution. The Resistance being an obsolete ironclad, several things were required to be executed on board to enable her to represent a modern battle ship attacked under approximate conditions. The bunkers below the armor shelf on the port side were accordingly made to represent the actual coal defense which is now applied for the protection of the boilers and machinery of a ship of war against submarine attack. The bunkers were fitted at Devonport with an iron longitudinal bulkhead, which divided them into two equal compartments. The one contiguous to the skin plating was filled with coal, due precautions being taken against firing by the provision of ventilating tubes. By these means there was a thick protection of coal sandwiched between the inner bunker and the wing passage. The whole port side of the ship was also defended against torpedo attack by Bullivant's service wire nets boomed out to the distance of 30 feet. This was the distance which previous trials had abundantly proved to be safe against the destructive force of a Whitehead torpedo; but the weight of such booms and the necessary working gear render them unhandy, cumbrous and burdensome, and the main object of the experiment was to ascertain whether the length of the booms could not be reduced without danger to the vessel attacked. As the purpose was to accurately ascertain the effect of a palpable hit, some sacrifice of practical conditions had necessarily to be made to ensure the hit being delivered precisely where it could inflict the most mischief. In actual warfare, it is presumed that the burst of a Whitehead torpedo would prove fatal to a ship wherever it came in contact with it; and although the projectile occasionally proves erratic from no ascertainable cause, save the proverbial refractoriness of inert matter, an ironclad presents so conspicuous a target that the torpedo would be almost certain to hit it somewhere. At the experiments on September 22, it was imperative and essential that the torpedo should hit her, not anywhere, but directly in a certain spot or compartment about 29 feet in length, and extending from the keel flat to the armor shelf amidships. To ensure accuracy, therefore, the old vessel was chained stem and stern in Portchester Lake, in the remote reaches of Portsmouth Harbor. She was a fixture, and in order that she should not have a chance of escape, the time of high

water was chosen, so as to avoid the deflective influence of currents, and also to prevent the destructive agent itself from being arrested in its course by lack of water and coming to an ignominious end in the mud. The instrument of execution selected for the occasion was the old 16-inch Whitehead torpedo. An obsolete torpedo was chosen because, although it may not pursue quite so straight a course through the water as a modern one, it carries considerably more in its head, its full charge of gun cotton being 91 lb. as compared with the 65 lb. of the modern 14-inch Whitehead. The torpedo was also fitted with a new pistol trigger, which is exceedingly sensitive, and explodes the charge upon traversing the meshes of the netting. The Vesuvius torpedo vessel was at a comparatively remote distance to the westward. The effective range of the improved Whitehead is understood to be 600 yards, but as it was expedient for many reasons to attack the net defenses of the Resistance at close quarters, the Vesuvius got underway, and, when passing her at a distance of 100 yards, discharged the projectile. The path of the torpedo through the water was clearly indicated by the air bubbles which it threw up, and though straight, its progress was undeniably deliberate. The torpedo struck the defenses a little forward of the target, but, though the visual force of the explosion was very great, those who expected to see the destruction of the old Resistance were disappointed. As soon as the fountain of water thrown up had subsided, it was manifest that the netting had served the intended purpose, and that, so far as could be seen, the ironclad had not only survived the attack, but remained uninjured. The nearest boom had been unshipped from its support, but the whole of the others remained intact. The meshes in the immediate vicinity of the burst had been carried away, but the area of positive destruction was so exceedingly limited that a second discharge would have proved just as harmless, unless it happened to have passed through the rent in the defenses inflicted by the first. Of course, the exact amount of dislocation on board can only be known after a careful survey, but so far as could be seen the ship was undamaged. The length of the booms will be gradually diminished until the vessel succumbs to the attack. The only foreign representative present at the trial was the German naval attaché. The torpedo experiments were resumed September 24 and resulted in serious damage to the old ship. So far as the experiments had previously proceeded, the results obtained had been little more than verifications and amplifications of the submarine mining data derived from the operations against the Oberon; but last Friday an important step in advance was made, and it was evident to all that the final stage in the endurance of the ship was near at hand. The former experiment had shown that the progress of a locomotive torpedo could be effectually arrested by the ordinary service protective nets now in use, and that the burst of a full charge of gun cotton at the theoretical distance of 30 feet from the ship's side was perfectly harmless. The attack was advanced to closer quarters, and as the value of the nets had been demonstrated, it was deemed no longer necessary to employ costly Whiteheads in the assault. A fixed charge of gun cotton representing the normal explosive energy of a Whitehead was accordingly slung from the booms at a distance of 20 feet from the skin plating (10 feet nearer than before, and submerged at a depth at which a torpedo would be set, and afterwards electrically exploded from a cutter. The explosion produced the usual detonation and spout of water, but its force expended itself in the air without inflicting any perceptible damage to the old hulk, which still continued to hold its own. A second charge of the same character and weight was afterwards sunk 5 feet nearer the ship, that is, 15 feet from the side, and exploded in a similar way. In this case the differences were manifest and significant. Though the volume of water thrown up was about the same, the detonation was less diffused, and, whereas the previous spout was perfectly clean, the outer ridges of the dome in this instance were discolored with mud, and presented a very vague outline. It was evident that considerable work had been performed and that the energy of the burst, being confined to some extent by the proximity of the ship, had rebounded from the harbor bottom. The Resistance, which was held down by four anchors, did not rock, but the shock on board must have been very severe. It appeared, too, at the time, that the explosion had damaged the vessel, as she seemed soon afterward to give a slight list to port, but, as she is divided into numerous water-tight compartments, even had the charge blown a hole in her, her heeling over would not be great. She was, however, greatly strained and shaken, and, though the booms remained in place, and none of the bottom skin was displaced, it began to leak until eventually the wing passage in wake of the target compartment became filled with water, and several runlets found their way into the bilges. During Friday night the water rose 5 in. an hour, and, although thirty men were engaged at the pumps, and were subsequently increased to close upon 300, they could not keep the water under. The diver, on being sent down to examine her sides and keel, reported that the main injury done was the straining of one of her plates; but it has now been ascertained that one of her Kingston valves was also extremely damaged, and the repairs will necessitate a postponement of the further trials. At five o'clock on Saturday morning, the large crew had the utmost difficulty in keeping the vessel afloat until half past seven, by which time she was towed up the harbor and hastily put into dock. Considerable interest was shown in the operation, and many naval officers awaited the clearing of the dock in order to inspect her hull; but a casual observation revealed little damage, the inrushing water being attributed more to the injury to the Kingston valve than to the straining of plates. When her defects have been made good, the Resistance will be taken back to Portchester Creek, where the experiments will probably culminate in her being blown up.

NORDENFELT VERSUS HOTCHKISS GUNS.—Some important trials have been made

at St. Petersburg with quick firing guns of the Nordenfelt and Hotchkiss systems, the weapons used being the 57-millimeter (2¼-inch) caliber. The results of the trial are stated to have been in favor, in every respect, of the Nordenfelt gun. The Nordenfelt gun fired 30 rounds per minute against 20 rounds with the Hotchkiss gun. The penetrative power of the Nordenfelt projectiles was far in excess of that of those used with the Hotchkiss arm, and in proportion to their respective initial velocity, which was 2,050 feet for the Nordenfelt and 1,800 feet for the Hotchkiss gun. The Nordenfelt gun also excelled its rival with regard to precision. Whilst the Hotchkiss projectile did not hit the target, which was 1,800 meters (slightly over a mile) distant, that from the Nordenfelt gun hit it nine times out of ten. A very interesting experiment was made with the two guns, four targets, placed at 600, 800, 1,000 and 1,200 meters respectively, being fired at. The Nordenfelt gun fired 15 rounds in 30 seconds, changing the target at each round, and made nine hits. Under the same conditions, the Hotchkiss gun fired only 11 rounds in 32 seconds, and hit the target only twice. It will thus be seen that, in quick firing, exact aiming at changing targets between each round is much easier with the horizontal and vertical gearing of the Nordenfelt system than with the lever arrangement of the Hotchkiss gun.

## BOOK NOTICES

ALBUM OF CRANE DESIGNS. Published by the Yale & Towne Manufacturing Co., Stamford, Conn.

This, although an advertising pamphlet, is almost a treatise on cranes. The brief preface gives a classification and some general directions regarding selection and use of cranes, and ninety plates fully explain the construction of the many kind built by this company.

PHYSICAL LABORATORY PRACTICE. By A. M. WORTHINGTON, M.A. London: Rivingtons. Price, $1.80.

This little book is full of excellent suggestions for teachers. Although most of the experiments are familiar to American teachers, yet as the descriptions given are for the benefit of the learner, the writer, while dwelling especially upon the choice of methods and pointing out the various sources of error, has given the book a value which would otherwise be wanting.

A small equipment only is needed for such a course in practical physics. The present treatise is called a *first* course, which suggests more to come. We have no doubt a further course will be welcomed by teachers who try the present book.

The typography is good and the illustrations are exceedingly well designed.

SHORT LECTURES TO ELECTRICAL ARTISANS. By J. A. FLEMING, M. A. London: E. & F. N. Spon. Price, $1 50.

This work presents in familiar language enough of the theory of electrical science to supplement the practice of artisans who are already engaged in some branch of electrical work. So special attention is given to the principles underlying modern electrical engineering. The reader is supposed to have some familiarity with the technical terms and with the proper use of common forms of electric and magnetic apparatus.

The whole is given in the form of lectures, of which there are nine. The first deals with Magnets, Lines of Magnetic Force; lecture 2d, with Electric Induction; 3d, Electro-Magnets and Magnetization; 4th, Electro-Magnets and Induction Coils; 5th, Electric and Magnetic Measurements; 6th, Instruments for Measuring Electric Quantities; 7th, Measurement of Electromotive force and Resistance; 8th, Primary and Secondary Batteries; 9th, Electro-Motors.

The book will be serviceable to the class for whom it was written.

ELEMENTS OF GEODESY. By J. HOWARD GORE, B.S., Professor of Mathematics in the Columbian University. New York: John Wiley & Sons. 1886. Price, $2.50.

This is a handsome volume of 280 pages octavo. The subject matter falls into two main divisions—the field work and the office work The treatment is very disproportionate, the field work receiving only about 75 pages. This is by far the most important part of the subject, and has not as yet been adequately treated by any American writer. To be satisfactory it must be done by one who has had a large and varied experience, as it is altogether outside the province of the mere compiler.

The second part contains a clear presentation of the elementary principles of the reduction of a triangulation. It is full enough for the class room.

On the whole we think that the author in compressing a subject so large as Geodesy into less than 300 pages has attempted an impossible task Besides superficial treatment of most subjects, many omissions must necessarily occur. Nothing, for example, is said on precise leveling, and next to nothing on the measurement of vertical angles.

We must commend the care with which the proof-reading has been done.

THE SEPARATE SYSTEM OF SEWERAGE: ITS THEORY AND CONSTRUCTION. By CADY STALEY, President Case School of Applied Science, Cleveland, O., and GEO. S. PIERSON, C E.

This book has a place in the literature of Sanitary Engineering, if for no other reason, because it gives a full, free and unbiased discussion of the separate system from the practical standpoint. The arguments for the necessity of sewerage systems, and for the advantages of the separate system of house drainage, are well stated and not too strongly put. But the strong point of the book is its eminently practical treatment of the subject. The authors have had considerable experience in designing and constructing systems of sewerage for small cities and large towns, and the results of that experence are here given with clearness and in sufficient detail to make the book an excellent text book for the education of city authorities to the necessities of the case in their respective cities. The idea of the specifications presented is good, and the set is probably a copy of one prepared for actual construction. One might

wish some statement as to the practicability of holding contractors to the strict terms of the specifications, which sometimes seem to be a little more strict than could actually be enforced. But the error, if any, is on the right side. The detailed statements of cost of the separate system as constructed in various cities, and the comparisons with other systems are timely, and of much use in presenting the subject to doubting City Fathers.

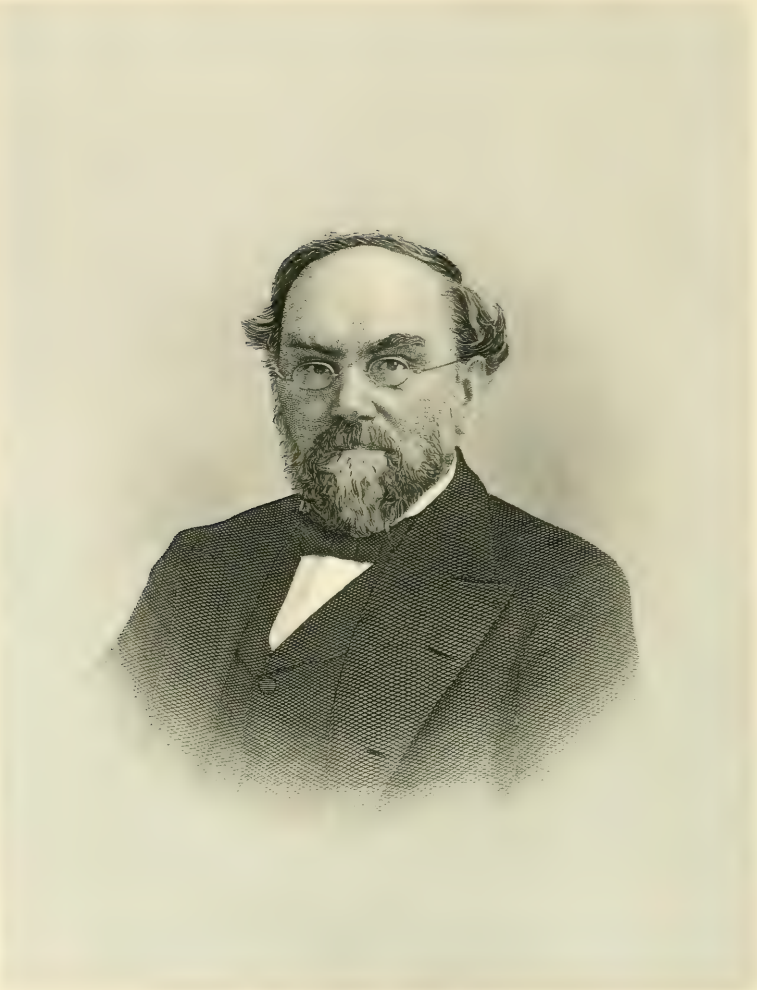
The hints on house drainage and plumbing find their proper place in the book. They might well have been more extended, for a system of drainage which is good so far as its public portion is concerned may be entirely spoiled by faulty design or construction in the parts which are private property.

The appearance of the book is all that could be wished—beautiful paper, presswork, type, plates, arrangement. There is but one inconvenience, the plates are not all numbered, and consequently one cannot turn very readily to a plate desired.

## MISCELLANEOUS.

Welding by Electricity.—Professor Elihu Thomson, the electrician of the Thomson-Houston Electric Company, of Boston, U. S. A., has invented a process of welding any metal or two dissimilar metals together by means of the electric current, and this forms a new application of electricity which bids fair to be as widespread as any of the present uses of electricity furnished by the dynamo. The process is based on the principle that the electrical resistance at a break is greater than any other portion of a conductor; and its application consists in applying the two pieces of metal together and passing a heavy alternating current through the juncture, and the heating at this point due to the excessive resistance fuses the surfaces to a solid union. The apparatus consists of an iron ring, a portion of which is wrapped by a number of turns of fine wire which is part of a circuit conducting an alternating current, which can be varied by means of resistances. Around another portion of the iron ring are a few turns of a large copper bar, the ends of which are attached to a copper clamp; the secondary current is completed whenever any two pieces of metal are secured between the jaws of this clamp, and the current is so great that the electric energy is converted into heat at the union between the two pieces to be joined. The process is almost instantaneous, and the heat is so localized that it does not affect the portions of the article in the vicinity of the joint. As a test of the process, broken blades of penknives and scissors were joined together without affecting the temper of the steel and showing no indications of the treatment, except a narrow dark line at the point of fracture. At the electrical works of the company it is used to join the ends of wires in winding coils, making a perfect butt weld of the same size and electrical conductivity as other portions of the wire, but its application in all forms of mechanical work is almost limitless; it is not confined to small work, such as joining the ends of wires for electrical purposes or for continuous wire drawing processes, but to such forms of butt welding chains, cask hoops, band saws, wagon tires and similar work. When large pieces of metal are used, the electrical work is supplemented by heating the pieces before electricity is used to accomplish the union.

A New Method of Protecting Iron.—M.A. de Meritens, the well-known electrician, has brought out a new method of protecting iron. The article to be protected is placed in a bath of ordinary or distilled water, at a temperature of from 70° to 80° C. (158° to 176° Fahr.), and an electric current is sent through. The water is decomposed into its elements, oxygen and hydrogen, and the oxygen is deposited on the metal, while the hydrogen appears at the other pole, which may either be the tank in which the operation is conducted or a plate of carbon or metal. The current has only sufficient electromotive force to overcome the resistance of the circuit, and to decompose the water, for if it be stronger than this, the oxygen combines with the iron to produce a pulverulent oxide, which has no adherence. If the conditions are as they should be, it is only a few minutes after the oxygen appears at the metal before the darkening of the surface shows that the gas has united with the iron to form the magnetic oxide, which it is well known will resist the action of the air and protect the metal beneath it. After the action has continued an hour or two, the coating is sufficiently solid to resist the scratch brush, and it will then take a brilliant polish. The depth of penetration is shown by the following fact. A gun barrel was oxidized, and then the magnetic coating was completely removed by emery, until the surface again became white. It was again returned to the bath, and immediately on the passage of the current the black color again reappeared. If a piece of thickly rusted iron be placed in the bath, its sesquioxide is rapidly transformed into the magnetic oxide. This outer layer has no adhesion, but beneath it there will be found a coating which is actually a part of the metal itself. In the early experiments with this process M. de Meritens employed pieces of steel only. But when he turned to objects in wrought and cast iron, he found that he no longer was successful, for the coating was not fast and came off with the slightest friction. After many trials with currents of different electromotive force, he reversed the order of affairs, and placed the iron at the negative pole of the apparatus after it had been already applied to the positive pole. Here the oxide was reduced, and hydrogen was accumulated in the pores of the metal. The specimens were then returned to the anode, when it was found that the oxide appeared quite readily and was very solid. But the result was not quite perfect, and it was not until the bath was filled with distilled water in place of that from the public supply that a perfectly satisfactory result was attained. The process, it will be seen, is perfectly simple, and demands but little skill in its execution. Now that dynamo machines have superseded batteries as sources of electricity, all that is required is a tank, a quantity of distilled water, and a little power to drive the machine. By placing a number of baths in series, and increasing and diminishing their number, the electromotive force of the current can be regulated without any arrangements of artificial resistance.



D. Van Nostrand

VAN NOSTRAND'S

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## DAVID VAN NOSTRAND.

David Van Nostrand was born in the city of New York, December 5, 1811. He was the son of Jacob and Harriet Rhoades Van Nostrand. His father was of pure Holland extraction and his mother of pure English, a union calculated to transmit to its offspring the best traits of the two races to which is due that combination of enterprise and conservatism, of refinement and integrity which have given New York City such a prominence in the annals of the State and country.

Though originally of Long Island, his father removed early to the metropolis, where, in time, he became a successful merchant. Here eight children were given to him, of whom David was the fifth. Here in the year 1821 he died, devolving upon his widow the sole responsibility of the care and education of five daughters and three sons, the subject of our memorial being at the time but ten years of age. A woman of exemplary piety, excellent education and vigorous intellect, Mrs. Van Nostrand proved equal to the task, and before her own death, had the great satisfaction of seeing all her children reach adult years and enter upon their several paths in life, bearing characteristics of which any mother might be proud.

As a child, David was noted for his love of books, giving to them, in preference to the usual sports of boyhood, his leisure hours. To that habit possibly was due in part his inability, even in the vigor of his manhood, to endure long-continued physical fatigue. He was educated at "Union Hall," a famous classical school at Jamaica, Long Island, at that time under the charge of Dr. Eigenbrodt. An active brain, quick to perceive and comprehend, with an exceptional memory, made study a mere pastime to the youth, and his progress therein easy and rapid. When but eight years old his instructor paid him the compliment of a prize for his attainment in the Greek language, and at fifteen he was graduated from Union Hall with a high reputation for scholarship, well grounded in the elements of an English and classical education, ready to enter upon a collegiate course. Though it was the wish of the mother that her eldest son should devote his life to the service of the church, this promising scholar seems to have chosen a business career in preference to the advantages of a liberal education, prompted thereto, possibly, by an impatient spirit of youth, eager to make its way in the world without waiting through years of college training. At the age of fifteen he entered the establishment of Mr. John P. Haven, a prominent bookseller and publisher of New York. The duties of this new sphere of life, so consonant to his tastes, seldom proved irksome, and recurring intervals of leisure,

morning and evening, for indulging his passion for reading, gave a zest to his labors. Though but a lad, his willingness, aptitude and devotion to the business gave him a rapid insight into all its details, and a familiarity with its multiplicity of volumes. So much was he liked and trusted by the head of the publishing house, to whom his assistance soon became almost indispensable, that at the age of eighteen, when the resumption of his course of studies was seriously contemplated, Mr. Haven, rather than lose his services, promised him a partnership in the business when he should reach twenty-one years of age—a promise faithfully kept.

Though his more intimate friends and his family regretted that Mr. Van Nostrand failed to achieve a collegiate education, in the belief that he would have been successful in any profession, there can be little doubt that he chose a business suited to his tastes, for he had a craving for books, and reading was the one supreme delight of his life. So well established, when he had but just reached the age of manhood, in a congenial calling, married to a daughter of the Rev. Isaac Lewis, D.D., a prominent divine of that period, his future seemed full of promise. But by strange vicissitudes of fortune, one disappointment followed quickly upon another, changing for years the tenor of his life. As early as 1834, some changes made by Mr. Haven in his business arrangements induced the withdrawal of Mr. Van Nostrand, leaving him to commence anew. Holding to the occupation for which eight years of experience with close application had eminently fitted him, he entered into partnership with Mr. William Dwight. Not long after this change had been effected he lost his young wife, to whom he had been married only eighteen months. A man of strong feelings, this first great sorrow of his life depressed his spirits, checked his ambition and seemed for a time to render him indifferent to his business interests. Scarcely had he recovered from the effects of this domestic calamity, when all branches of trade and commerce were suddenly prostrated by the memorable crisis of 1837, which so far reduced the capital of his firm by losses incurred, as to lead to its dissolution, and thus, for a time, his connection with the book business wss dissevered. While with Mr. Haven, Van Nostrand made the acquaintance of cadet J. G. Barnard, who was graduated at the U. S. Military Academy in 1833, a mere lad of eighteen years, yet one of the most brilliant scholars that institution had produced since its foundation. When the youthful Lieutenant of Engineers was soon after assigned to duty in New York harbor, congeniality of tastes and mutual esteem brought these two friends into close companionship, and established their life-long intimacy. Later, when Capt. Barnard was stationed at New Orleans, in charge of the defensive works of Louisiana and Texas, he invited Mr. Van Nostrand to visit him, to be his groomsman at his forthcoming wedding, and to remain with him as his clerk of accounts and disbursements. An excellent accountant, ready with his pen as at figures, with good business experience, he was well suited to his duties, nor did he find them unpleasant, in view of his pleasing relations with his early friend. Nevertheless the position did not fill the measure of his ambition. It was too limited and unpromising a sphere for a person of his intelligence and ability. So he gave it up, but not without regret at parting with his companion of many years. He always referred to this sojourn in New Orleans as a pleasant episode of his life. There can be little doubt that the association produced a decided influence upon Mr. Van Nostrand's future career, by developing his natural taste for military and scientific subjects, and by extending his acquaintance among men eminent in those branches of knowledge. So on his return to New York he commenced the importation of military books for officers of the U. S. Army, followed soon by orders from private individuals and from academic institutions for foreign books of science. Establishing his business house at the corner of John street and Broadway, when his importing trade was well developed he added thereto his own publications. Army and navy officers, civil and mechanical engineers, architects, professors, authors, and scientists were his frequent callers, for his familiarity with the extensive technical literature embraced in his business, his courteous welcome to visitors, and readiness to give

information to all inquirers, soon won him popularity and made him life-long friends. Even before the recent war for the Union, his importations and publications, meeting a public need, had grown quite up to his room capacity on Broadway, and his correspondence reached to the great book marts of the Old World, as well as to the principal cities of the United States, which he supplied with the greater portion of technical books needed in those branches of science not excluded from his catalogue. His military books were not restricted to importations, but included a large number of publications, some of which were valuable and costly editions. His naval publications were more limited in number. Nevertheless his list of authors records the names of several distinguished officers of the navy. It was, however, by his large importation and publication of works on pure and applied science that Mr. Van Nostrand acquired prominence among the noted publishers and booksellers of the world. To enumerate his valuable publications would require the reprint of a large portion of his long catalogue, not within the scope of this brief notice

In 1869, finding his accommodations on Broadway too restricted for his extensive business, Mr. Van Nostrand removed to No. 23 Murray street, a building which extended through the block to Warren street. The upper story was utilized for storage, the second for the display of his large collection of standard works, embracing the whole range of physics, engineering, civil and mechanical, mining and metallurgy, and architecture, with every branch of military and naval art. Thus in twenty years his patient and intelligent devotion to his business had made him the most prominent importer and publisher in the United States of books purely scientific and military.

In 1869 Mr. Van Nostrand commenced the publication of an engineering magazine, for the most part an eclectic, but open to mathematical discussions and scientific investigations bearing upon questions of undoubted interest to the engineer. It was conducted during the first year by the late A. L. Holley. Since 1870 it has been edited by Professor Plympton. Intended for a standard work to rank with the ablest magazines of the kind published abroad, which it has undoubtedly done from the beginning, it could not assume the popular form, or find space for text-book instruction and mere practical details, but has been, for the most part, restricted in its original contributions, as in its selected articles, to productions of a high order of merit, touching important engineering problems of the day. Too restricted and technical to meet a popular demand, its circulation, though reaching remote countries, has been limited mostly to an advanced class of engineers.

The general prosperity of our country for nearly a decade after the War for the Union had ceased, since 1875 has been followed by a depression, equally far-reaching, from which the business interests of the land are still emerging with but slow progress. Mr. Van Nostrand felt this depression seriously, as it bore so heavily upon builders, engineers, metallurgists, and the workers in every branch of mechanical art, largely his customers, and the more, that, for nearly all this period, he was more or less an invalid, unable to give that close attention to his affairs, more than ever needed, which he had done in antecedent years. The duties of a successful publisher involve unremitting attention as well as ability and sound judgment. To determine the absolute merit and probable reception, if given to the public, of the many proffered manuscripts on technical subjects, is not an easy task, even for an expert with a life-long experience and undoubted ability.

Mr. Van Nostrand gave an impulse to scientific investigation in this country by importing so large an assortment of books, embracing every branch of physics in its extended sense, open to the inspection of all interested therein, and by encouraging native talent to make itself known ; and among those who have since attained distinction, many will remember the friendly advice that stimulated their ambition and started them as authors. In fact, the influence of his publishing house, ably and liberally conducted, could not be otherwise than beneficial to a people rapidly growing up to independence of thought and action in every department of knowledge. His creditable part in this advancing growth, so fully and generously acknowledged abroad, as

evinced by the complimentary notice in *Trübner's Record*, is equally appreciated on this continent, at the centers of scientific progress, and by all those who are cognizant of his life-long labors. Nothing better attests the intellectual material advance of our people, during the past quarter of a century, than this progress in physics and its application to the mechanical arts, by the great army of workers, from the humble artisan, through all grades, up to the master minds engaged in searching out and making known Nature's hidden truths.

Mr. Van Nostrand, in his devotion to his profession, did not lose from sight the welfare of his native city, but, on the contrary, was interested in several organizations instructive to its people. A member of the Historical and of the Natural History Societies, a subscriber to the *Art Union*, a fellow of the Academy of Design, and a member of the Metropolitan Museum of Art, he contributed his portion to these valuable institutions for many years, not forgetting those devoted to charitable purposes. One of the originators of the Union League Club, formed to encourage patriotic sentiment among the people of New York, and to uphold the National Government in its struggle to preserve the Union, he gave much time, as an active member of the Executive Committee to further those ends. His pride of ancestry induced him to join the St. Nicholas Society early in life, and he was one of the founders of the Holland Society and the St. Nicholas Club. The Century Club was, however, his favorite resort. There he met, more than elsewhere, his old-time associates and valued friends, and it was a matter of regret to him, in his later years, that illness often prevented his attendance at its monthly meetings.

Mr. Van Nostrand's two junior brothers were graduates of the University of New York, the elder taking orders in the ministry, the younger devoting himself for a time to the law, but neither held fast to his original profession. Rhodes Van Nostrand, after a little law practice, took up civil engineering as a profession more congenial to his tastes, but died in the prime of his manhood. Compelled by ill-health to withdraw from his ecclesiastical ministrations, the Rev. Jacob Van Nostrand was for many years an instructor in the New York Institution for the Deaf and Dumb, and later Superintendent and President of a similar institution in Texas. He was a thoroughly educated, able scholar, of a benevolent, sympathetic disposition, who devoted his energies to his profession, the education of the deaf mute. The oldest brother outlived the two younger as well as his sisters, though for several years an invalid.

Although his school days were ended before he was sixteen years old, Mr. Van Nostrand's education, self-imposed, was continued through life. From his youth upwards his evening hours were for the most part given to reading, whereby he became well versed in general literature, and fairly so in the civil and military histories of the leading nations of the world. He was well posted as to the current topics and interests of the day, and more especially within the limits of the English-speaking people. His knowledge of books and authors was remarkable, for before disease had begun its inroads his memory seemed to retain almost every impression that it had ever received. He was reticent in reference to his own accomplishments, for vanity was not one of his characteristics. He wrote tersely, but with great fluency, his letters being models of directness of thought and purpose. It is to be regretted that he did not, from his youth upwards, devote some of his leisure hours to authorship, as his habit of continuous reading cultivated his perceptive and receptive faculties, at the expense of his reflective and imaginative. He was recognized as a man of intelligence and ability, not only by his intimate friends, but by the many educated people with whom he came in contact, in social and in business life. For nearly thirty years before Gen. Barnard's death, the intimacy of their younger days was renewed, nor was it the less agreeable from their changed circumstances, the one standing at the head of the principal scientific publishing house in America, the other in the foremost rank of engineers and mathematicians of our country. It was a friendship that strengthened with years, for Mr. Van Nostrand was one of those who never lose their hold upon real friends, nor fail of appreciation under

the critical eye of intimacy. He cared little for companionship with commonplace people, but sought rather the society of men of character and intellgence. Refined in his tastes, temperate in all things save in his passion for reading and music, and familiar with the productions of the masters of that art, society life, in its general acceptation, was not to him a necessity. Its excess was wearisome, for he possessed within himself, more than most men, resources for his own entertainment. He was a lover of the fine arts in their fullest signification, and saw in the wonderful specimens of exquisite design and workmanship of the artisan the touch of inspiring genius, as in the masterpieces of painting, sculpture and music.

A few years after his re establishment in business, Mr. Van Nostrand was married to a daughter of E. W. Nichols, in former days a well-known merchant in New York.

Mr. Van Nostrand's sedateness and solidity of character did not in the least render him taciturn. Though a ready talker when interested, his conversation did not incline to the mirthful and humorous. Appreciative of true wit, a coarse sentiment was repugnant to his native delicacy, and in my long acquaintance with him I cannot recollect that one ever fell from his lips. Charitable by nature, he contributed, as far as he was able, to the necessities of the unfortunate. To his sisters he was a kind brother, to his mother a devoted son. So long as his health permitted he was regular in his attendance at the services of his church, holding to his faith with that tenacity which he evinced in all the ways of life, for firmness of purpose was his by right of birth.

In person Mr. Van Nostrand was rather below the medium height, but his broad shoulders, grand head, and strongly-marked, intelligent face, gave him an air of solidity and dignity, so that among notable men he could not fail to attract observation. Though a great sufferer through the last nine years of his life, from chronic, and at times from acute ailments, he did not relinquish his business, but patiently struggled against his disease, even against hope. From January 18th until June 14th, the day of his death, he was confined to his rooms, and mostly to his bed. His devoted wife, herself an invalid, was his only attendant, through this prolonged period of suffering. Her faithful and loving care alleviated the tedium of many weary days of pain, her sympathies alone could reach the heart of the dying sufferer. That he lived so long was due to her constant presence and unremitting solicitude and attention. How much will he be missed from the circle of his dear friends and life-long companions, who fully appreciated his sterling worth, integrity of character, and other attractive qualities! To them it is satisfactory to know that their friendship was given to an earnest, true-hearted gentleman, in public devoted to a useful and honorable calling, and sustaining, in his private relations, those virtues that elevate the standard of social life.

CONTRIBUTED BY A FRIEND.

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# NOTES UPON THE MORE IMPORTANT FEATURES OF LARGE RESERVOIRS FOR IRRIGATION.

BY G. TORRICELLI.

Translated from Il Genio Civile, for Abstracts of the Institution of Civil Engineers.

The author, having recently had to visit and study a large number of reservoirs, has noted some points which he thinks deserving of attention.

The weight of masonry dams has generally hitherto been taken at 125 lbs. per cubic foot in calculating their stability. This is too little, and from 137 to 143 lbs. is the weight usually adopted now. On the other hand 62.4 lbs. per cubic foot is still taken as the weight of water, whereas the author's experiments have clearly demonstrated that turbid water, such as is often found in reservoirs, weighs from 63 to 75 lbs. per cubic foot. While, therefore, 62.4 lbs.

may safely be taken for cases where flood-waters are excluded, a higher value should be adopted where these are admitted to the reservoir. It has been found on calculating the stability of certain dams, taking 68.6 lbs. as the weight of water, that the pressures and tensions at the external and internal faces of the dams are from one-fourth to one-third greater than when 62.4 lbs. is adopted.

Three dams in Algeria have recently failed, the Habra in 1881, and the Cheurfas and Sig dams in February, 1885. At Hamiz the water was admitted into the reservoir in 1884, but the dam having shown symptoms of failure, the water was at once run out, and an immense retaining wall was built to arrest the movement. The water was admitted into the Cheurfas reservoir in January, 1885, and it at once began to make its way through the permeable ground at one end of the wall. The sluice at the bottom of the reservoir could not be opened, and after a time a large quantity of earth was washed away, carrying with it some 30 feet of the dam. The water washing through this great aperture caused a flood in the river below. Some distance down stream the Sig reservoir was situated, and the flood pouring down topped the dam by 18 feet and overthrew it. When the Hamiz dam failed it was subject to a pressure of 157 lbs. per square inch and a tension of 43 lbs. per square inch, which the author considers too high for mortar, which, though of excellent quality, had not had sufficient time to set. The author points out that a slight increase in the height of the water in the reservoir above that for which a dam is calculated produces greatly increased strain upon the work, and therefore means should always be adopted to insure that the water will not rise above the intended level, and he recommends that dams should be built circular on plan, so as to act as arches, particularly if the foundations are not very solid, and instances that of Chéliff, which is 59 feet high, and has twice had water running over it to a depth of 13 feet. This dam is founded upon beds of sandstone, alternating with clays, which formed a very unreliable foundation nevertheless the dam has never shown any sign of failure, though subjected to severe compressive and tensile strains, and the explanation of this fact is that the dam is formed in an arc of a circle of 492 feet radius, the length of the arc being 260 feet.

The highest earth dam in the world, with the exception, perhaps, of some in India, is said to be that of Oued Meurad, in Algeria, which has a height of 95 feet. This was completed in 1864, and is in very good condition. A few fissures have appeared at the top and have been filled in with masonry. The bank stands upon a bed of basaltic rock, no excavation having been made to receive it. About 3 gallons of water per second leak through, but without endangering the bank. It was constructed in layers, but these, instead of being horizontal, were normal to the outer slope. When the bank had been completed up to a certain height, the reservoir was allowed to fill; this caused the bank to settle down, and when it stopped settling the work was resumed and the bank completed. This is a somewhat dangerous method of construction, but produces a very solid bank.

Another remarkable dam is that of St. Christopher, upon the Marseilles canal. This was originally simply a bank of rough stone 65 feet high, for carrying the canal across the valley, and constructed with very little care, without any intention of using it as a reservoir dam. When it was determined to adapt it to this purpose the water-tight lining of the canal was removed, and the turbid water allowed to sink into the dry stonework. This produced considerable settlement, but at the same time filled up the cavities with deposit. Water was then gradually let into the reservoir. At first large quantities made their way through the dam, but the amount of leakage diminished by degrees, and the inner face of the dam was then covered with good masonry 10 feet thick at the bottom and 1½ foot at the top. This was expected to render it water-tight, but did not have this effect, and upon readmitting the water, large fissures appeared on the face, particularly near the bottom. Several rows of piles were then driven near the foot, and the cracks were filled up, and the bank is now practically water-tight.

A novel method of construction has

been adopted at the Puentes reservoir in Spain. The rocks on either side of the valley are very solid limestone, but the bottom of the valley consists of sand and gravel, which rest upon a bed of marl. Arches have been thrown across the valley abutting against the rocks, and the dam, which is of masonry, is supported by them, and only the filling underneath the arches rests upon the bad foundation.

The author points out that storage reservoirs have a very beneficial effect upon climate, as has been proved in Algeria, where the result of storing up the flood-waters in winter and using them for irrigation in summer has been the drying up of the marsh lands and laying them under cultivation, with a marked improvement in the health of the country.

Masonry dams frequently leak a good deal when first constructed, and this need not cause alarm, as by degrees the leakage diminishes. If, however, the ground is permeable, a serious amount of water is lost by filtration round the ends and underneath the dam. When flood-waters are stored in reservoirs, a large amount of deposit takes place, and this may be disposed of for irrigation in winter, when it serves as a manure, but in summer clear water only must be used. Special arrangements for discharging the water are necessary in such cases.

The silting up of irrigation reservoirs is one of the most serious problems in connection with them, and it is sometimes thought that where the reservoirs are fed by mountain torrents bringing down stones and boulders, they would be filled up with these materials, but the author's observations lead him to the conclusion this is not the case, but that detritus of this description is deposited in the beds of the streams above the reservoir, and only fine stuff is carried into it. This latter, however, amounts to a very considerable quantity. The annual amount of deposit at the Habra reservoir is 4.44 cubic feet per acre of gathering ground; at Sig 4.05 cubic feet; at Tlélat 24 cubic feet; and at Djidionia 43 cubic feet. Various methods of washing out the deposit are discussed in the paper, which concludes with remarks upon the value of water for irrigation, and a table giving particulars and cost of twenty-one reservoirs in different parts of the world.

## DEFLECTION OF A BRIDGE TRUSS.

By HARRY SHERIDAN.

Written for Van Nostrand's Magazine.

Suppose a triangular truss, resting on two supports, required the deflection at any point, which practically is the center of the truss. The bending of the truss under the action of a uniform or concentrated load causes the chords to assume curved forms, which, with no essential error, may be taken as arcs of circles.

It is evident that the greatest deflection will occur at the center of the bridge, since the bending of the moment curve is generally greatest at that point. Therefore we will now investigate a formula for the deflection of the center of a truss.

Let then R = radius of curvature at C.

$$z = \tfrac{1}{2} \text{ the span} = \frac{l}{2}$$

$y$ = deflection at C.

From the equation of the circle,

$$z^2 = 2Ry - y^2, \text{ or } y - R = \pm\sqrt{R^2 - z^2} \qquad (1)$$

Now since R is very large compared with $y$ or $z$, the first member, and consequently the second member of (1) must be negative quantities. Therefore we must only use the lower sign in the second member.

$$\therefore \quad y = R - \sqrt{R^2 - z^2} \qquad (2)$$

Again, it is well known that with a small curvature, $\frac{1}{R}$ or the reciprocal of the radius of curvature is very approxi-

mately represented by $\frac{d^2y}{dx^2}$ which is the differential equation for the deflection. But by the common "Theory of Flexure" demonstrated by writers on Strength of Materials,

$\frac{d^2y}{dx^2}=\frac{M}{EI}$ in which M is the bending moment at the point under consideration E is the Coefficient of Elasticity usually taken at 25,000,000 lbs. per square inch and I the moment of inertia of the cross section of the truss, approximately supposed to be constant.

Therefore, substituting these values in equation (2) and remembering that $z=\frac{l}{2}$, we have

$$y=\frac{EI}{M}-\sqrt{\left(\frac{EI}{M}\right)^2-\frac{l^2}{4}} \qquad (3)$$

But $M=hT=$ stress in member into height of truss.

Also by a recent investigation of Prof. H. T. Eddy, of the University of Cincinnati, I, the moment of inertia of a truss at any section, is equal to the square of the height into the area of cross section of chord member opposite the panel point under consideration, *i. e.*, $I=h^2A$. Substituting for M and I their values (A being the area of metal in chord member), we have

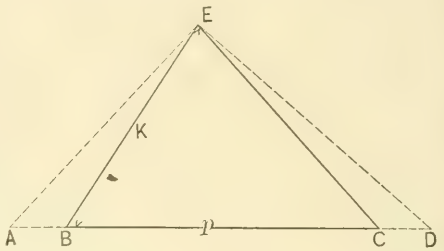
$$y_\Delta=\frac{Eh^2A}{S}-\sqrt{\left(\frac{Eh^2A}{S}\right)^2-\frac{l^2}{4}}$$ measured in inches. (A)

This is a very simple formula, much more so than the one advanced by Mr. G. F. Swain in the Journal of Franklin Institute for 1883. His formula $y_\Delta=\Sigma\frac{tTl}{EA}$ in which $t$ is the stress brought to bear upon the members of a truss by reasons of a unit weight applied at the point where the deflection is desired, and the other letters refer to the same things as ours do, is evidently a tedious and lengthy one, since the stress due to the unit weight is to be found in each member separately and then a big summation is to be performed. In our formula, only one member is to be computed, viz.: $\frac{Eh^2A}{S}$ since it also appears under the radical as a squared quantity.

Applying our formula to the chord members of a bridge for which the deflection has been computed in the same volume, we find a difference of .007 of an inch. A very inappreciable amount.

Heretofore, especially in the treatment of girders, the effect of the web members on the deflection has been neglected. We will, however, endeavor to investigate this effect and then deduce a formula for the elongations of the various web members, which being added to formula (A) will give the total deflection of the bridge truss.

In the figure, let BEC be the original




panel, BE=EC=K the diagonals, and BC=$p$=panel length. Now by reason of the lengthening of the lower chord BE will become AE, EC will become ED and BC will become AD.

Let BE=EC=K and AE=ED=K′ and AB=CD=amount of lengthening of each chord. If $x$=lengthening of each diagonal=K′−K and $n$ = number of diagonals ∴ $nx$=total elongation of diagonals=$n$(K′−K).

The angular length of the lower will be

$$a=2\sin.^{-1}\frac{l}{2R},\quad \text{but}\quad R=\frac{EI}{M}$$

$$\therefore a=2\sin.^{-1}\frac{lM}{2EI}=2\sin.^{-1}\frac{lT}{2EAh}$$

and the length in feet will be represented by

$$L=Ra=\frac{2EI}{M}\sin.^{-1}\frac{lT}{2EAh}$$

$$=\frac{2EAh}{T}\sin.^{-1}\frac{lT}{2EAh}$$

∴ L−$l$=total change in length of chord

$$=\frac{2EAh}{S}\sin.^{-1}\frac{lS}{2EAh}-l$$

$\therefore$ represented by $\lambda$ this change per panel and $m$ = number of panels

$$\therefore \lambda = \frac{2EA\Delta}{Tm} \sin.^{-1} \frac{lT}{2EA\Delta} - p \text{ since } l = mp \quad (B)$$

From the figure

$$K' = \sqrt{\Delta^2 + \tfrac{1}{4}(p+\lambda)^2}$$

$$\therefore K' = \sqrt{\Delta^2 + \tfrac{1}{4}\left(\frac{2EA\Delta}{Tm} \sin.^{-1} \frac{lT}{2EA\Delta}\right)^2}$$

But $nx = n(K' - K)$

$$= n\left\{\sqrt{\Delta^2 + \left\{\left(\frac{EA\Delta}{Tm}\right) \sin.^{-1}\left(\frac{lT}{2EA\Delta}\right)\right\}^2} - K\right\} \quad (C)$$

It is seen that (C) is also very easy to compute, since $\frac{EA\Delta}{T}$ is the only term involving large multiplication.

Now adding together formulæ (A) and (C), we get

$$\Delta_c = \left\{\frac{EA\Delta}{T} - \sqrt{\left(\frac{EA\Delta}{T}\right)^2 - \frac{l^2}{4}}\right\} + n\left\{\sqrt{\Delta^2 + \left(\frac{EA\Delta}{Tm} \sin.^{-1} \frac{lT}{2EA\Delta} - K\right)^2}\right\} \quad (D)$$

Formula (D) can be applied at any panel point and the deflection accurately determined.

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## ITALIAN RAILWAY CONSTRUCTION.

Translated from Centralblatt der Bauverwaltung, for Abstracts of the Institution of Civil Engineers.

It is especially in earthwork and tunnel construction that Italian railway engineering presents characteristic features, more particularly in South Italy and Sicily, where large formations of shifting sand and clay and continual landslips are encountered, as well as crevasses and soil disintegrated by volcanic action and earthquakes. Although behind some other countries in the development of their railway system, the Italians have by no means copied the practice of other nations; but though still largely dependent on foreign material, have introduced distinguishing features in design and practice, testifying to great inherent energy and resources.

The marked alternation, in the southern part of the peninsula, of dry and wet seasons, transforms these frequent landslips and drifts of loose soil, now into sandheaps, now into waterfalls; and consequently the foundation of embankments is a matter of great difficulty, often requiring piling and other preparations of the surface, with ample provision—by revetment walls, culverts, and tumbling-bays—for the regulation of streams which vary, according to the season, from a rivulet to a torrent. The slopes of the banks have also frequently to be entirely cased in fascines and rubble, or the whole bank interlaced with these; in some cases the bank is formed with internal cross-culverts and drains and masses of dry filling, to enable the unavoidable saturation to be dealt with.

In iron bridge work, which is distinctly characteristic of French influence, lattice girders are most commonly employed, and are now largely manufactured at Castellamare. In bridges of more than one span, great insistance is made on the use of continuous girders.

The construction of some of the tunnels offers points of great interest. The Marianopoli tunnel, on the Santa Caterina and Rocca-palumba line (Sicily) is about $3\frac{3}{4}$ miles long, and passes partly through shifting sand and clay, and through hard clay, gypsum and chalk. It was driven from five shafts, varying in depth from 300 to 820 feet, the daily advance at each point averaging 5 feet. The thickness of the lining (the crown, sidewalls and invert forming a continuous curve) varies greatly with the different strata, and in many places counterforts are also necessary. The subjoined dimensions show the section of the tunnel:

| | Ft. | Ins. |
|---|---|---|
| *a*. Height from invert to rail level.... | 3 | $2\frac{1}{8}$ |
| " " rail level to horizontal axis..... | 6 | $6\frac{3}{4}$ |
| " " horizontal axis to crown | 11 | $5\frac{5}{8}$ |
| Total height, invert to crown..... | 21 | $2\frac{1}{4}$ |
| " " rail level to crown.... | 18 | $0\frac{3}{8}$ |

*b.* Width at rail level..... 13 $10\frac{1}{2}$
" " horizontal axis..... 18 $4\frac{1}{2}$

*c.* Radius (1) crown, 7 ft. $4\frac{1}{4}$ in.;
arc subtended, 57° 8′
Radius (2) springing, 10 ft. $3\frac{1}{4}$ in.;
arc subtended (each side), 38° 50′
Radius (3) side walls, 14 ft. $4\frac{1}{4}$ in.;
arc subtended (each side), 29° 8′
(22° 36′ above, and 6° 32′ below, the horizontal axis.)
Radius (4) invert, 9 ft. $1\frac{7}{8}$ in.;
arc subtended (each side), 166° 56′

*d.* Points of intersection of radii on vertical center-line;

Above the horizontal axis.
Radii 1 and 2..... 3 ft. $2\frac{3}{4}$ in.
" 2 " 3..... 1 ft. 10 in.
Below the horizontal axis.
" 3 " 4..... 0 ft. 7 in.

*e.* Thickness of arch (all round) varies from 1 ft. 3 in. to 4 ft. 6 in.

Amongst recent performances of the Ferroux boring machine is the Cocullo tunnel, 3,828 yards long, on the line from Rome to Sulmona. The tunnels on the Novara-Pino line are described below.

In permanent way, flanged rails on transverse wooden sleepers are universally adopted: the rails (steel) weighing generally 73 lbs. per yard, in lengths of 29 feet 6 inches. On the South Italian railways still greater lengths are adopted. In 1883 there was in the whole country only one switch of English make; but in the Turin Exhibition of 1884 several were shown by the Alta Italia Railway Company.

Amongst the most remarkable lines recently constructed may be mentioned first the Benevento, Campobasso and Termoli railway, branching from the Naples and Foggia line, through the high-lying districts of the Appennines to a more southerly point on the Adriatic coast. The length is $105\frac{1}{2}$ miles, and the steepest gradient 1 in 40; the summit of the Apennine watershed is reached at San Giuliano (38 miles) at a height of 1,700 feet, the highest point of the line being 2,848 feet above the sea. Between Campobasso and Termoli the soil is frequently very treacherous, occasioning several slips in tunnels and earthworks; and at Cascacalende only a temporary wooden station was erected, as the whole site was in movement.

The Aquila, Rieti and Terni line, 64 miles in length, also traverses the Apennines, the steepest gradient being 1 in 28.5. The summit of the line is reached at Sella di Corno, 3,248 feet above the sea; from Antrodocco, in the Velino valley, the line rises 919 feet in less than 7 miles by zigzag curves, half of this length being in tunnel.

The third line across the Apennines, began in 1882, connects Rome with Sulmona, on the east coast, and has been constructed as a main line. Its length is 105 miles, and the works fully rival those on the St. Gothard line. This railway crosses two distinct chains of the Apennines, between which Lake Fucino is situated; the western summit of the line at the Monte Beve tunnel, 4,170 yards in length, is at a height of 2,625 feet, the eastern summit and watershed at 2,959 feet, being at the Cocullo tunnel previously referred to. The steepest gradient is 1 in $33\frac{1}{3}$.

The remaining line of particular interest is the Novara-Pino railway, forming part of the main line to the St. Gothard, from Genoa and the west coast, and joining the Novara and Avona line at Oleggio. Passing along the east side of Lago Maggiore, it is joined by the Monte Ceneri line from Como to Milan. The line extends to the frontier, a length of $40\frac{1}{2}$ miles, of which 8.39 miles are in tunnel. The steepest gradient is 1 in 129; and there are eighteen tunnels, two hundred and sixty-two small and twenty-two large bridges, including one over the Ticino near Sesto Calende with three spans of 263, 312 and 263 feet respectively.

The line is remarkable for the speed with which it was completed: the whole work having been finished in sixteen months. One of the longest tunnels (Varalla-Pombia) 2,931 yards in length, partly in moraine, was pierced by hand-labor from the two faces and six shafts; the heading was completed in six and a-half months, and the work finished within twelve months. The Laveno tunnel, 3,210 yards long, in chalk and dolomite, and for which access either by lateral or vertical shafts was impossible, was bored entirely by Ferroux machines from the two mouths; the time occupied being nearly fifteen months, the average daily progress 6 yards, and greatest progress 7 yards. Both these tunnels are lined with brickwork.

# COMBUSTION, WITH SPECIAL REFERENCE TO PRACTICAL REQUIREMENTS.*

By FREDERICK SIEMENS.

From "Iron."

In all heating operations, the main object is to produce the greatest amount of effective work with economy of fuel, material, and labor. In order to do this, it is of the utmost importance that combustion should be as perfect as possible. This, however, would not alone in all cases meet practical requirements, the form and dimensions of the furnace and many other points having also to be considered. The author read a paper two years ago before this institute, in which he described a method of working regenerative gas furnaces by employing radiant heat alone within the heating chamber. On that occasion he drew attention for the first time to an important point connected with combustion, which he proposed to treat more particularly on the present occasion, viz.: that a flame requires free space for development, if it is to burn properly and effectively. He then showed, from results obtained in practice, that a flame burning within an enclosed space should be directed so that whilst in active combustion it does not come into contact either with the sides or roof of the furnace, or with the materials contained therein, as when flame is allowed free space in which to burn, and is not interfered with by solid bodies, not only is there an increase of the work performed, but that work is accomplished in a better manner, and a considerable saving of fuel, furnace material, and other advantages are realized. Since that time this system of applying radiant heat, which it is now preferred to describe under its more general term as heating with free development of flame, has been largely adopted, and the author's theoretical investigations have been borne out by the results of practical experience. It is necessary in an investigation of this kind to commence with a consideration of combustion from a theoretical point of view, and the theory which best explains the nature of flame is the one by which it is regarded as a rushing together of gases, the molecules of which, being chemically excited, are in violent motion towards or against one another. Such motion is a primary condition of combustion, which cannot take place without it, so that anything interfering with the motion of the gaseous particles prevents that chemical union which exhibits itself as combustion. In order to insure perfect combustion, the following means have to be adopted:

1. The gases must be supplied in the exact chemical proportion in which they are required for combustion.

2. The gases must be brought together in such a manner that the different molecules which have to enter into combination may readily do so.

3. Everything must be avoided which interferes with the motion of the gases while combustion is proceeding.

The first proposition is well understood, the proportion of gases which enter into combination having been settled by chemical analyses of the products of combustion; but in its application serious practical difficulties occur in supplying the combustibles uniformly, more especially when solid fuel is employed. This difficulty disappears to a great extent, if not altogether, when solid fuel is converted in the first instance into gas, as the supply of gaseous fuel may easily be regulated, and thus kept nearly uniform. The facility of controlling the supply of gas to a furnace is one of the reasons for the economy which arises in the employment of gaseous instead of solid fuel. A great saving of labor may also be effected if the transformation of the solid fuel into gas is properly carried out. As regards the second point, it is difficult to lay down any general rule for the way in which the fuel, and the air necessary for its combustion, should be brought together, as this will depend on the special object in view, and the particular work which has to be performed. Theoreti

* Paper read before the Iron and Steel Institute, Oct. 7, 1886.

cally, a thorough mixture of the gas and air before combustion, of which the best example is the well-known Bunsen burner, may be regarded as a solution of this difficulty, but in practice, in the great majority of cases, such a complete mixture is for various reasons quite inadmissible. A Bunsen burner is only advantageous when a small surface has to be heated by direct contact of flame, as proved by the incandescent gaslight, and by certain operations in the laboratory and household; while, when large spaces have to be heated, as is generally the case in furnaces, it is always advantageous to use a large luminous flame, which radiates heat. The flame of a Bunsen burner being almost non-luminous, owing to free carbon not being liberated during combustion, has but little radiating power, and must in consequence transmit its heat by direct contact only. The transmission of heat by means of direct contact of flame is, in most cases, unsuitable, as was shown in the author's paper already referred to. It is wasteful, and tends very much to destroy or injure the furnaces in which it is used, as well as the materials operated upon. Although the Bunsen burner appears so simple from a theoretical point of view, and is undoubtedly found to be so in practice for certain purposes, it is quite unfit for most metallurgical operations, especially those conducted upon a large scale.

As, therefore, in the generality of cases it is not advisable to mix gases before combustion, means have to be adopted to bring them together, as rapidly as possible, at the beginning of combustion. It is also necessary that the resulting flame should have a high radiating power, as it is by the radiation of the flame that heat is best transmitted to the walls and roofs of furnaces and to the material under treatment. Furnaces in which solid fuel is burnt necessarily produce radiant heat in the ordinary or natural process of combustion, but the real cause of the efficiency of such furnaces does not seem to have been appreciated, although it was known from experience that the only coals fit to be used in them were those supplying large quantities of heavy carburetted hydrogen gas, liberating in consumption much carbon, which tends to produce a luminous flame. The very best coke was found to be entirely unfit for the same purpose, although the highest temperature can be obtained by its use, if the materials to be heated are inserted in the incandescent coke itself, as is proved by the melting of steel in pots by the old method. There is no particular difficulty in producing radiant heat in ordinary furnaces if proper coal is employed; but it is quite otherwise where gas is used, and in the regenerative gas furnance the manner in which the gases are brought together is a matter of the greatest importance. If the mixture is too intimate, a short flame is produced, having great heating, but very little radiating power, whereas, if the gases do not properly combine, perfect combustion cannot take place. A great loss of heat is thus occasioned, together with other disadvantages, which will be referred to later. A mean between these is what is required, whereby good combustion is secured, producing intense heat, and at the same time a flame of great radiating power.

The way in which the gas and air should be brought together for combustion depends upon various circumstances —chemical, physical, structural and economical—such as the quality of the gas employed, the temperature required, the size of the furnace-chamber, and the particular work to be performed. The gas is generally supplied through a horizontal slit in the side of the furnace-chamber, above which the air enters through a similar slit of somewhat greater area, overlapping the gas port on either side. Gas being of lower specific gravity than air, tends to rise through it, while the air sinks into the gas, thus securing, in most cases, a sufficient mixture. The efficiency of this arrangement greatly depends upon the relative temperature of the gas and air, the specific gravity of gases being very much affected by their temperature. If, for instance, air only is heated before admission into the furnace chamber, the specific gravities of the hot air and cold gas will be more nearly equal, and the gases not permeating one another, no proper mixture can take place, and, consequently, combustion will be imperfect, causing a great reduction in the working power of the furnace, with other resulting disadvantages. It will be interesting to consider for a moment the cause of flame becoming lumin-

ous. This luminosity is due to free carbon, liberated by the hydro-carbons in the flame, being heated up to the temperature of the flame itself; these solid particles, becoming incandescent, act like tiny incandescent gas lights, each particle of free carbon throwing out heat and light in all directions, until consumed and converted into carbonic acid gas, which is transparent, and therefore does not radiate light and heat, although its temperature may have increased during the change. The free carbon is always the last component part of the flame to burn, and, in cases of imperfect combustion, instead of becoming incandescent and luminous, it is precipitated as soot when deposited in chimney flues, and as smoke if carried along with the products of combustion, which, issuing from chimney-tops, is so very objectionable in our towns and manufacturing districts.

The third means necessary for adoption in order to insure perfect combustion formed the subject of the paper already referred to; it is not, considered by itself, of the highest importance, as regards every case of combustion, but has a direct influence upon the first and second points, because neither the employment of gases in proper proportion, nor their proper mixture, if sufficient to insure perfect combustion if the disturbing influence of surfaces is allowed to interfere to prevent combination, or to dissociate particles of gas already combined. The author's former paper was so far incomplete that it did not describe the objectionable effects resulting from the influence of solid bodies on combustion, or contain any sufficient theoretical explanation to account for that influence. Besides this, the subject of dissociation, which is of such importance in practical metallurgy, was entirely left out of consideration, partly because of its difficulty, partly because the author was not satisfied with any theory of its action that had been proposed, but principally because he wished to confine himself mainly to a statement of the actual results he had obtained in the practical working of furnaces. The author has since fully referred to the influence of dissociation upon the temperature and working of furnaces, in a lecture he delivered to the members of the Royal Institution of Great Britain in May of this year. He then showed that surfaces not only interfered with combustion, for the reasons already explained, but also that, if heated, they facilitate dissociation; that, in fact, dissociation, which has hitherto been brought about by the influence of heat alone, was in reality caused by the action of heated surfaces upon the combined gases; or, at all events, that in the absence of surfaces the temperature of dissociation would be very much higher.

It would lead the author too far if he were to repeat upon the present occasion all the circumstances and considerations which led him to the conclusion then brought forward; he would propose to confine himself to a few points which appear to him sufficiently conclusive. In the first place it must be explained that nearly all the physicsts who have experimented on dissociation have made use of small vessels or tubes, of special material, which had to be heated to the temperature at which dissociation of the gases experimented upon would set in. Although the particular materials chosen—mostly clay, porcelain, or asbestos—have no direct chemical action on the dissociated gases, yet the influence of surfaces in general, and especially of highly-heated surfaces, have been entirely overlooked. Heat expands the molecules of gases, and thus tends to weaken the chemical affinity of their atoms, until, at a certain high temperature, expansion overpowers chemical attraction, and dissociation takes place; but if highly heated surfaces are present, which tend to attract or condense one or other of the elements constituting the gas experimented upon, dissociation is facilitated, and will necessarily occur at a much lower temperature. That this is a correct theory is confirmed by the circumstance that, if the vessels or tubes used for the experiments are made of rough or porous material, or, still better, if they are filled with rough or porous materials, such as broken porcelain or asbestos, dissociation is much facilitated. Until, therefore, experiments intended to prove dissociation are made in an open space containing no heated surfaces, it will be impossible to ascertain the real temperature of dissociation, all calculations hitherto made being too low. The highest dissociation temperatures which

have been recorded are those of Professor Bunsen, and he obtained them mainly because his experiments did not require heated surfaces; but even his results cannot be considered correct, as the cold inner surfaces of the tubes in which he exploded the gases prevented their perfect combustion, for the reason already stated. Still, the Bunsen experiments are of the highest value as indicating the means by which real dissociation temperatures may be arrived at. This was explained in the author's lecture at the Royal Institution, and illustrated by diagrams.

Hitherto physicists have been satisfied to prove dissociation by showing that a flame became longer with increase of temperature. It was maintained that, as the temperature of the flame increased, dissociation set in more and more, thus causing an extension of the flame, combustion and dissociation being repeated over and over again. As this was really the case, the experiment was so far conclusive, only the real cause of the dissociation which took place was not sufficiently understood. The experiments made to prove dissociation by an increase in the length of the flame, having been made in narrow tubes, like the other experiments, were influenced by the action of the inner surfaces, which action is mainly the cause of this kind of dissociation, as is proved when the dissociating influence of the surfaces is removed. This is the case in the regenerative gas-burner which has been set up and lighted. It will be observed that while the flame is comparatively cool it is long, whereas with increase of temperature the flame becomes gradually shorter and whiter, thus illustrating the fact that a flame, as its temperature increases, becomes shorter if it is not impeded by surfaces, which prevent combustion and help dissociation. This burner is supplied with ordinary town gas, and serves to show the effects which may be produced when all the means available to insure perfect combustion are taken advantage of. Nothing has been done to the burner since it was lighted, the gas supply remains as it was, and the chimney being independent of the flame which burns free, all conditions remain constant except the temperature; this becomes very intense, much higher, indeed, than that of the flame, burning in the narrow tubes, in which the dissociation experiments were made. Flame burning in narrow tubes may be compared with the old-fashioned furnace system, and taken as an example of working the flame by causing it to strike on the walls and roof of the furnace chamber and the material it contains. By these means a long flame of low temperature is produced, which may even extend as far as the top of the chimney, destroying everything with which it comes into contact. The flame here exhibited may, on the contrary, be compared to a furnace working with free development of flame, the latter being intensely hot, and giving out its heat in the furnace chamber entirely by radiation. The furnace itself will not be injuriously affected for a much longer time than formerly, and the materials it contains will show a marked improvement in quality. The fully-burnt products of combustion having radiated out the greater portion of their heat, deposit the remainder by contact, either directly—as, for instance, in a boiler—or indirectly, as in the regenerative chambers of a Siemens furnace.

It will be seen from what has been said that solid substances have a twofold influence on combustion. In the first place, they hinder combustion, because they interfere with the rapid motion of the gases necessary for combustion; and, in the second place, they cause dissociation, as explained in the author's lecture before the Royal Institution, and by so doing, of course, a great amount of heat is lost. The dissociation caused by hot surfaces is of various kinds, and takes place at different temperatures. At a comparatively low temperature dissociation of hydrocarbons takes place, the carbon being liberated in the solid form as soot. At a moderately high temperature carbonic oxide is dissociated into solid carbon and carbonic acid gas; at a higher temperature the products of combustion begin to dissociate, steam spliting up into hydrogen and oxygen, and lastly, at a still higher temperature, depending upon the kind of surface with which the products of combustion came into contact, carbonic acid splits up into solid carbon and oxygen. From this it will be seen that dissociation has the effect of setting carbon free, and to its influence the formation of smoke is

largely due. This smoke is a serious disadvantage, not only after it has left the chimney, but even to a greater degree before it has left the furnace chamber in which it is formed, as will be seen from the following consideration.

It has been found in practice that in a large furnace where a voluminous flame impinges on the sides and roof and on the material it contains, even that part of the flame which is not in direct contact with the surfaces does not radiate out nearly its full amount of heat. As flame is quite transparent for light and heat, the inner surfaces of the furnace chamber, and the materials it contains, ought to get the full benefit of the radiative power of this part of the flame, and that this is not the case can only be explained by the circumstance that these surfaces are enveloped in a dense cloud of dissociated carbon, which prevents the heat rays from reaching the surfaces. There can be no doubt that radiant heat has always been a very useful factor in heating operations whenever the construction of the furnaces, &c., admitted of it. But the author believes he has shown in the above remarks that sufficient attention has not hitherto been paid to the very detrimental effect on combustion itself, as well as on the work done, when the radiative power of the flame is in any way interfered with, so that it cannot be developed to its fullest extent. He hopes also to have made it clear that complete combustion is impossible whenever the live or active flame is allowed to come into contact with any solid surface, and that such solid surface will always suffer when so impinged upon—not, as has been hitherto believed, by the action of heat alone, but also by mechanical and chemical action of such flame. As flame is nothing but molecular motion of combining gases, this circumstance alone proves the necessity of not interfering with such motion, whilst the moving molecules, although indefinitely small, are so numerous and move so rapidly, that they represent an amount of energy which, acting constantly, must in time destroy any surface or object exposed to it, besides which the flame has most probably a chemical influence that tends to assist this process of destruction.

The author wishes to draw attention to the gas-burner exhibited, which was fully described at a meeting of the Gas Institute, and is similar in principle to the regenerative gas-burners brought out some years ago, which are now manufactured in various forms, and used extensively for lighting purposes. This particular burner is designed for warming rooms by means of radiant heat in the same way as the ordinary English fire. There is, however, this difference between the two, that with this burner heat is radiated in a more useful manner, being distributed uniformly throughout the room. Very active ventilation is insured by its use, it is not expensive to maintain—consuming about 50 cubic feet of gas per hour, which is sufficient to warm a small sitting-room—and is specially economical as regards labor, as no handling of coals, ashes, or soot is required, and smoke is entirely avoided. In an ordinary fireplace the heat, which is not radiated out into the room, but is carried away with the products of combustion into the chimney, is lost, whilst it is utilized in this case to heat up the air required for combustion, whereby the temperature, and consequently the heat radiating power of the flame, is much increased. This process goes on in a progressive ratio; for as the temperature of the flame increases, so does that also of the air supplied to the burner, and thus it can be safely asserted that nearly all the heat produced by combustion is eventually radiated into the room.

The author has exhibited this burner at work, and has drawn so much attention to it because it gives the best possible illustration of the conditions under which combustion can alone be perfect. It also shows to how great an extent radiant heat can be applied, and how important a part it plays in all operations of warming, heating and transmiting heat. For these reasons the author recommends this burner to the consideration of the members, as supplying information in the best and most easy manner regarding the requirements of large furnaces, with which it is so difficult to make experiments and obtain data. In each case the flame is not permitted to come into direct contact with any surfaces whatever, while the heat still remaining in the non-luminous products of combustion is abstracted by direct contact in the regenerators, heating up the

air required for combustion, which air, being non-luminous, can only be heated by direct contact, as radiant heat has no effect in heating air, just as heated air cannot be made use of to supply radiant heat.

The analogy being so perfect it will be readily seen how well the requirements of combustion for the production of radiant heat can be studied by means of this little burner. It is by means of radiant heat alone that nature warms us, and thus becomes the source of the development of all organic and inorganic matter. We should imitate nature, and employ radiant heat for artificial warmth, as well as in the arts and manufactures.

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## ON THE BEHAVIOR OF CAST-IRON, WROUGHT-IRON AND STONE COLUMNS IN FIRE, AND UNDER RAPID COOLING (BY WATER).

By J. BAUSCHINGER.

From Abstracts of the Institution of Civil Engineers.

In 1884 new regulations were issued by the Berlin police authorities with regard to the use of cast-iron columns in new buildings, or alterations of old ones. According to these, "cast-iron columns which are not protected from the direct action of fire may no longer be employed under the main walls of buildings of which the lower floors are used for business and storage purposes and the upper floors as dwellings. In place of them will be allowed: (*a*) wrought-iron columns; (*b*) cast-iron columns, which are surrounded by an irremovable casing of wrought iron insulated by an air-space from the column; (*c*) columns of stone set in cement."

The severe character of these regulations induced the author, at the instigation of Mr. Kusterman (the owner of a large foundry in Munich), to undertake a series of experiments in order to ascertain the behavior of columns of various materials, but especially cast and wrought iron, under the action of fire and rapid cooling by water. The regulations in question were the outcome of observations made after a large fire at a manufactory in Berlin, on the condition of the cast-iron columns used in its construction.

The author's experiments were made on columns of cast iron, wrought iron, and building materials of various kinds. The column to be tested was subjected, in the Werder testing-machine, to the compressive load it would have to sustain in actual use, and in this condition heated to the desired temperature, and then suddenly cooled by jets of water.

For the purpose of heating, the column tested was partially surrounded by a perforated wrought-iron trough, in which wood was burned. Owing to the nature of the arrangements, cooling could only be effected from the upper side, the position of the column being horizontal; but this corresponds with what actually occurs at a fire in the majority of cases. An arrangement for measuring the deflections of the column during the experiments, in two directions at right angles to each other, was made by means of wires attached to the former, and acting on index fingers placed at convenient distance.

The temperature of the material tested was measured by means of alloys having various melting points, the highest being 600° Centigrade.

Six cast-iron, three wrought-iron columns, and fifteen of various building materials were tested.

The results showed that cast-iron columns best withstood the action of the fire and water, continuing to support their load even when red-hot and already cracked in places, whereas wrought-iron columns collapsed entirely under similar conditions.

The building materials tested were granite, marble, tuff, dolomitic limestone, concrete, paving stone, granitic marble, various kinds of sandstone, and ordinary bricks. Of all these materials the concrete proved to be the best, and after this ordinary brick-work. The concrete column tested remained uninjured after exposure to the treatment for one hour and three-quarters. None of the natural building stones resisted the fire; granite was relatively the best, then tuff.

# HYPSOMETRY.

By IRA O. BAKER, C. E., Professor of Civil Engineering, University of Illinois.

Contributed to Van Nostrand's Engineering Magazine.

II.

## Chapter II.

### LEVELING WITH THE ANEROID BAROMETER.

### Sec. 1. The Common Aneroid.

§ 58. *Description.*—The aneroid barometer consists of a cylindrical metallic box, exhausted of air, the top of which is made of thin corrugated metal, so elastic that it readily yields to alterations in the pressure of the atmosphere. When the pressure increases, the top is pressed inwards; when it decreases, the elasticity of the lid tends to move it in the opposite direction. These motions are transmitted by delicate multiplying levers to an index which moves over a scale. A spring is sometimes inserted between the two ends of the vacuum chamber to reinforce the elasticity of the corrugated ends. Sometimes the vacuous box is not entirely exhausted, the object being that the enclosed air may reinforce the spring, "the air gaining elasticity as the spring loses, with increase of altitude." It is at least doubtful whether the spiral spring needs assistance, and therefore, whether the air is of any benefit; and it certainly introduces complications, owing to the effect of a change of temperature of the enclosed air

There are several forms of aneroids which differ in the mechanism employed to multiply the linear motion of the end of the vacuous box and to convert it into angular motion. Fig. 5 shows the mechanism of a common form; the outside case and the front face of the vacuous box is removed.

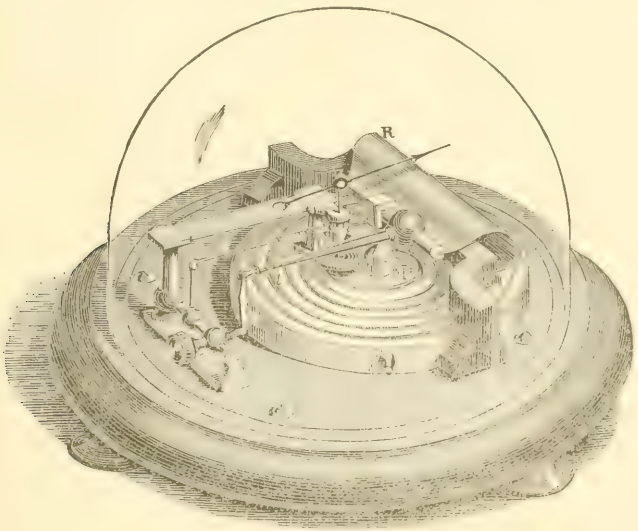



Fig. 5.

The instrument is graduated empirically by comparing its indications under different pressures with those of a mercurial barometer; the scale is marked to correspond to inches of the ordinary barometer column, the inches being divided into tenths, and the tenths usually into four parts. At the back of the instrument is a little screw which presses against one end of the exhausted box;

by turning this screw, the index can be moved over the scale, and the instrument may thus be made to agree at any time with a standard mercurial barometer.

§ 59. In many instruments there is an additional scale of altitudes in feet generally divided according to a table prepared for the purpose by Professor Airy. Such a table could be prepared by using any of the formulæ discussed in the preceding chapter by neglecting the corrections. Professor Airy used a formula similar to (11), and neglected the temperature term. When the aneroid has a scale of elevations engraved upon its face the approximate difference of height is obtained by subtracting the reading in feet at the lower station from that at the upper.

The use of such a scale leads only to rough approximations, as it is based on the assumption that certain differences of pressure correspond at all heights with the same differences of elevation. The scale of elevations can only be correct at some particular temperature, and hence in general a temperature correction must be applied. Some makers endeavor to eliminate this correction by making the scale movable. "The movable scale is unscientific and inaccurate." The best plan is to dispense with scales of altitude, whether fixed or movable, and calculate the heights.

§ 60. *Defects.*—The aneroid is a very convenient instrument and for a stationary instrument where nice readings are not required, it does very well; but for accurate hypsometrical results it is an inferior instrument. Its defects are:

1. The elasticity of the corrugated top of the vacuum chamber is affected by repeated changes in pressure. This will produce error in the scale readings.

2. It is usually claimed that, in consequence of not completely exhausting the vacuum box, the indications of the aneroid become independent of the effect of changes of temperature of the instrument. The best that can be hoped for is that for small changes the temperature correction is less than the error of observation. In instruments compensated for temperature, the effect of a change is sometimes the same as that in the mercurial barometer, and sometimes the reverse. The effect of the temperature on any particular instrument can be determined only by trial.

3. The different spaces on the scale are seldom correct relative to each other, owing probably to errors of observations and graduation, and possibly to differences of temperature and changes in elasticity. As a matter of fact, the scale is often only a scale of equal parts. The barometer scale is more accurate than the elevation scale, since the latter has all the inaccuracies due to the formula by which it is graduated, in addition to those of the instrument itself. For accurate work the aneroid should have a thermometer attached; then, before using it, it should be tested under an air-pump, together with a mercurial column, and its scale errors for different temperature and pressures determined.

4. The weight of the machine affects its indication, *i. e.*, the reading of the aneroid will differ when held in different positions. "In the best instruments this difference is sometimes as much as 0.008 of an inch, corresponding to a difference of elevation of about 8 feet." (Williamson).

5. Like all combinations of levers, screws and springs, the aneroid is subject to continual shifting of parts, when subject to the jars and jolts encountered in transportation and in use. The only remedy is frequent comparisons with a mercurial barometer.

6. The aneroid is deficient in precision, since the least reading is 0.025 of an inch, which corresponds nearly to 25 feet of elevation.

7. With most aneroids the spring ceases to act after the pressure has been lowered somewhat; that is, the instrument runs down. Before using the instrument, experiments should be made to determine the range of pressure to which it may be exposed before the spring ceases to act. In case an aneroid is to be used in an elevated region, if there is a mercurial barometer with the party, screw up the aneroid until the spring acts well and set it by the mercurial barometer, so that there shall be a difference of say one or two inches between them.

§ 61. "With all these defects a good aneroid is of much assistance on a survey or reconnoissance in mountainous districts, on side trips of one, or even several days' duration, when the instru-

ment had been previously compared with a standard mercurial barometer at various temperatures and in different elevations, and proper tables of corrections made. It is evidently important that there should be a good attached thermometer. It should be compared before and after it is used in that way, to see if the zero has not changed in the mean time, and if the agreements are satisfactory the results can be relied upon." *

§ 62. *Formulæ.*—From the readings of the aneroid at two stations, the difference of elevation may be determined by any of the formula of the preceding chapter, for any of the approximate formulæ are as accurate as the instrument.

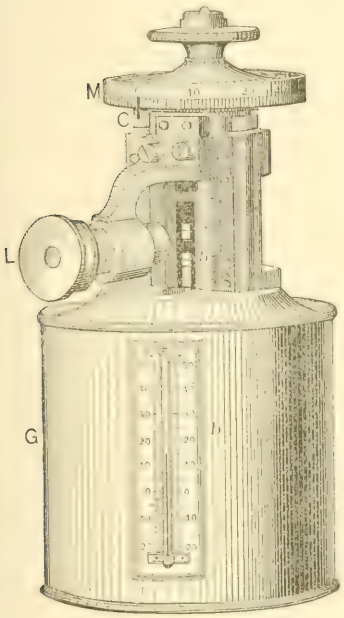



Fig. 6

A modification of Babinet's approximate formula (11), is most frequently used. The following is a very common form:

$$X = 54500\frac{H_1 - H'}{H_1 + H'} + \frac{T-55}{450} \pm 10 \pm \frac{X}{200}\dagger$$

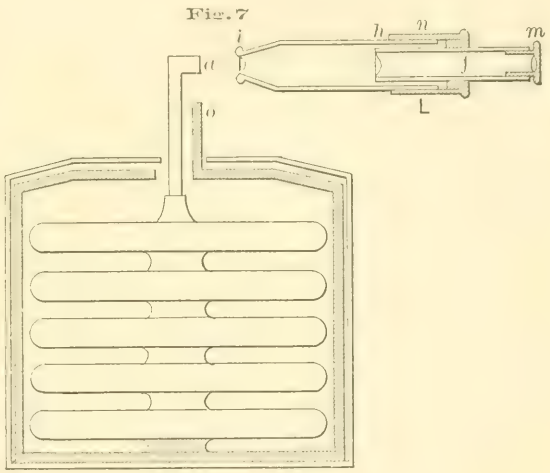
The last term is the supposed probable error due to the varying density of the air column, and the preceding term that due to the instrument itself. This formula is limited to difference of heights of about 3,000 feet.

* Williamson on the Barometer.
† U. S. C. S. Report, 1876, p. 352.

SEC. 2. THE GOLDSCHMID ANEROID.

§ 63. The common aneroid was invented by Vidi, of Paris, in 1847, and the defects of its complex levers have long been recognized. As early as 1857, Goldschmid designed a form of aneroid which sought to do away the transmitting and multiplying mechanism of the Vidi form. Figs. 6 and 7 are two views of one of the latest forms of Goldschmid's aneroids: Fig. 7 is a section through the compound vacuum chamber, the greater the number of boxes the larger the motion of the index *a*. The relative position of the movable index *a* and fixed point of reference *b* is observed by the telescope L (Fig. 6), the distance

Fig. 7




being measured by the micrometer M. The instrument is very delicate in its indications, but is liable to serious disarrangement by ordinary handling. Different manufactures have slightly different forms of the Goldschmid type, but all have essentially the same defects—are not able to stand ordinary use.

It is doubtful if there is any advantage in an aneroid as complicated as that shown in Figs. 6 and 7; it seems probable that no form can be devised which shall be both delicate in its indications and able to stand rough handling. The

chief advantage of the common aneroid is its portability, combined with moderate accuracy. The mercurial barometer and the aneroid supplement each other; the first is delicate and the second is portable. It is doubtful if the two qualities can be combined in a single instrument, or one obtained more delicate or more reliable than the mercurial barometer.

## Chapter III.

### LEVELING WITH THE THERMO-BAROMETER.

§ 64. *Theory.*—When water is heated, the elastic force of the vapor produced from it gradually increases until it becomes equal to the incumbent weight of the atmosphere. Then, the pressure of the atmosphere being overcome, the steam escapes rapidly in large bubbles, and the water boils. Since the temperature at which water boils in the open air depends upon the weight of the atmospheric column above it, and as the weight of the atmosphere decreases with the elevation, it is obvious that the higher the station, the lower the temperature at which the water will boil at that station. The temperature at which water boils under different pressures has been determined by experiment. It is then only necessary to observe the temperature at each station at which water boils, and by referring to tables similar to the above, find the corresponding height of the barometer, from which the difference of elevation may be computed by any of the formulæ previously given. Or, the temperature may be observed at only one point, and by using the mean pressure at the sea-level, compute the absolute elevation.

Or, finally, if the effect of variations in temperature, moisture, pressure, etc., be neglected, a table may be computed which will give, with the observed temperature of boiling water for an argument, the average approximate elevation of the station above the sea.

Table of Elevations Corresponding to Different Temperatures of Boiling Water.

| Boiling point. | Elevation above the sea | Boiling point. | Elevation above the sea |
|---|---|---|---|
| 190° | 11719 ft. | 208° | 2049 ft. |
| 195 | 8953 | 209 | 1543 |
| 200 | 6250 | 210 | 1021 |
| 202 | 5185 | 211 | 509 |
| 204 | 4131 | 212 | 0 |
| 206 | 3085 | 213 | −507 |

A table similar to the above, which depends upon a mean state of the atmosphere, cannot be very reliable, but it is as accurate as the observations themselves.

§ 65. *Description.*—This instrument is very simple in its construction, requiring only some means of immersing a sensitive thermometer in the steam which arises from pure water while boiling under atmospheric pressure.

The general arrangement consists of a closed vessel with a chimney with a combination of passage ways for the exit of the steam, somewhat like Figure 8. The bulb of the thermometer is thus immersed in a current of steam. The double passageway is to prevent condensation on the inner walls of the flue.

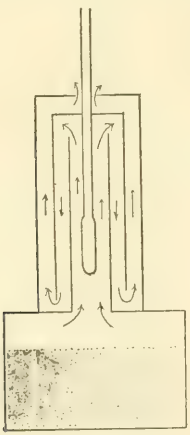


Fig. 8

§ 66. *Defects.*—The chief difficulty is in ascertaining with the necessary accuracy the true temperature of boiling water; an error of $\frac{1}{10}$ of a degree centigrade would cause an error of 70 to 80 feet in the final result. An observation of the boiling point, differing by $\frac{1}{10}$ of a degree from the true temperature, ought to be considered a good one. The accuracy is dependent upon the accuracy and sensitiveness of the thermometer, and is affected by the quality of the glass of the thermometer, the form and substance of the vessel containing the water, the purity of the water, the place at which the bulb

of the thermometer is placed, whether in the current of steam or in the water, the error of reading, displacement of zero point, &c.

Even if the above errors did not exist, this method would still be subject to all the chances of error which affect the measurements of heights by the barometer.

Nor is the thermo-barometer as convenient as either the aneroid or mercurial barometer, owing to the time required to start a fire, boil the water, make the observation and wait for the instrument to cool, and the difficulty of obtaining pure water. Also, altogether the apparatus makes quite a load to be carried from place to place.

Since the invention of the aneroid, the method of measuring heights by the temperature of boiling water has almost been abandoned.

## Chapter IV.

### TRIGONOMETRIC LEVELING.

§ 67. *Principle.*—Trigonometric leveling consists in determining the difference of level of two stations by means of the measured angle of elevation or zenith distance of one, and the known horizontal distance between them. The horizontal distance is usually given by triangulation.

This kind of leveling is peculiarly suitable for finding the heights of the stations of a triangulation survey, since the extra labor required to measure the necessary vertical angles is but slight.

§ 68 *Observations.*—The vertical angles are measured at the same time and with the same instrument as the horizontal angles. The instrument should have two opposite verniers or micrometer microscopes, and a sensitive level in a plane parallel to the vertical circle. It should be carefully adjusted for collimation, verticality of the vertical axis, horizontality of the horizontal axis of the telescope, and the verticality of the plane of the vertical circle. Matters relating to stations, towers and targets belong more particularly to triangulation and will not be discussed here. On account of the uncertainty of the action of the atmosphere, there is no hope to obtain as great accuracy in the measuring of vertical as in the horizontal angles.

All errors of the instrument, except those of graduation, will be eliminated by observing as follows:—sight upon a target, read the level and the circle; reverse in altitude and azimuth, point upon the station and read circle and level again. The half difference of reading, corrected for difference of level, is the zenith distance of the target. Shifting the circle and repeating would reduce the errors of graduation and observation, but these errors are generally so small in comparison with the uncertainties arising from refraction, that it is therefore better to measure the angles on different days, so as to obtain different conditions of the atmosphere rather than to take any great number of successive observations.

§ 69. *Refraction.*—Since the effect of atmospheric refraction is to elevate objects on the horizon, a correction for refraction must be added to the zenith distance as measured above. The uncertainty as to the amount of this correction is the great cause of inaccurate work in trigonometrical leveling. Refraction is so erratic in its character that no satisfactory method has yet been devised for determining it. The best that can be done is to observe only when the refraction has its least effect.

Therefore, since the accuracy of trigonometrical leveling is limited by our knowledge of the laws of atmospheric refraction, it will be necessary to investigate that branch before proceeding with the general subject.

### Sec. I. Coefficient of Refraction.

§ 70. *Definition.*—The angle of refraction divided by the arc of the earth's circumference, intercepted between the observer and the station observed is called the *coefficient of refraction.** That is, if C = the angle at the center of the earth subtended by the two stations, F = the refraction angle, and $m$ = the coefficient of refraction, then $m = \frac{F}{C}$. C can be found in arc from the expression $C'' = \frac{K}{\rho \sin 1''}$, in which K is the distance

* In the reports of progress of the U. S. Lake Survey and in Wright's Adjustment of Observations, a definition is given which makes the coefficient of refraction twice as large as the above. The definition as above seems to be the one most frequently used.

between the two stations and $\rho$ is the radius of the earth.

§ 71. *To find the Coefficient.*—The coefficient of refraction may be found in either of two ways, viz.:—I, from reciprocal zenith distances; or, II, from the observed zenith distances of two stations, the relative altitudes of which have been determined by the spirit level.

§72. I, *By Reciprocal Zenith Distances.*—In Fig. 9, if A and B denote the positions of the two stations, the angles which the observers attempt to measure are PAB and QBA. On account of the refraction of the atmosphere, the path of a ray of light from B to A will not be a straight line, but some curve more or less irregular; the direction in which B is seen from A will be that of a tangent, AT, to this curve. The line of sight from the other station will not necessarily be over the same curve.

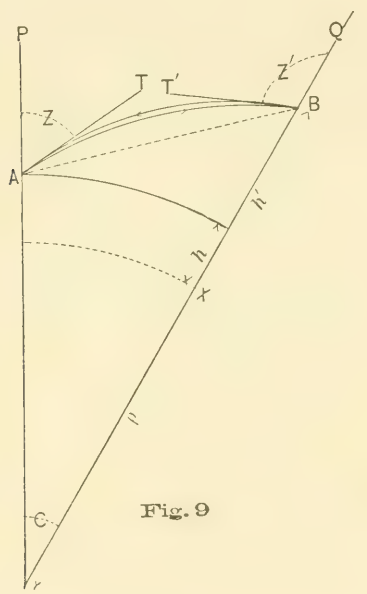


Fig. 9

Let $z$ and $z'$ be the observed zenith distances and $m$ and $m'$ the respective coefficients of refraction; $m$C and $m'$C are the refraction angles. From the figure

$$z+m\mathrm{C}+z'+m'\mathrm{C}-\mathrm{C}=180^\circ \qquad (19)$$

Since this equation contains two unknown quantities, it shows that observations over a single line will not give the coefficients; but in the reduction of a triangulation net, this equation may be applied to each line and the resulting equation solved by the method of least squares, thus obtaining the values of each coefficient, or at least a coefficient for each station.

However, such elaboration is of doubtful utility and is seldom practiced. It is usual to assume that the mean of a number of observations, taken under favorable conditions, will eliminate the difference of refraction which is found to exist, even at the same moment, at two stations a few miles apart. The observations should be simultaneous or nearly so. Under these conditions the coefficients at the two ends of a line become equal; *i.e.*, in the preceding formulæ $m'=m$. The error in this assumption will be greater as the distance between the stations is greater; it also increases very rapidly with the difference in elevation.

Making this substitution (19) becomes

$$m=\tfrac{1}{2}\left(1-\frac{z+z'-180}{\mathrm{C}}\right)^* \qquad (20)$$

§ 73. II, *By zenith distances, the difference of level being known.*—There are two cases; (1) single zenith distances and (2) reciprocal zenith distances.

(1.) Measure the zenith distance of the station, and from the known difference of level compute the true zenith distance; the difference between the true and computed zenith distances is the refraction angle, which, divided by the subtended angle, is the coefficient sought.

From Fig. 9

$$\frac{\mathrm{CB}-\mathrm{AC}}{\mathrm{AB}+\mathrm{AC}}=\frac{h'-h}{2\rho+h'+h}=\frac{\tan\tfrac{1}{2}(\mathrm{CAB}-\mathrm{CBA}}{\tan\tfrac{1}{2}(\mathrm{CAB}+\mathrm{CBA}} \qquad (21)$$

$$\mathrm{CAB}=180^\circ-z-mc$$
$$\mathrm{CBA}=z+mc-c$$

Substituting and reducing

$$\frac{h'-h}{2\rho+h'+h}=\cot.(z+m\mathrm{C}-\tfrac{1}{2}\mathrm{C})\tan.\tfrac{1}{2}\mathrm{C} \qquad (22)$$

$$\tan.\tfrac{1}{2}\mathrm{C}=\tan.1''\frac{\mathrm{C}''}{2}=\tan.1''\frac{k}{2\rho}=\frac{k}{2\rho}$$

$$h'-h=k\cot.(\mathrm{Z}+m\mathrm{C}-\tfrac{1}{2}\mathrm{C})\left(1+\frac{h'+h}{2\rho}+\frac{k^2}{12\rho^2}\right) \qquad (23)$$

* U. S. C. & G. Report, 1882, p. 182.

$$Z + mC + \tfrac{1}{2}C = \cot.^{-1}\frac{h'-h}{k}\left(1-\frac{h'-h}{2\rho}-\frac{k^2}{12\rho^2}\right) \quad (24)$$

from which $m$ can be found.

(2.) Also CBA=180°—(Z′+$m$′C); substituting this value in (21), rembering that Z′+$m$′C=$Z_0$′ and Z+$m$C=$Z_0$ and solving as before we get

$$\tfrac{1}{2}(Z'_0+Z_0) = \tan.^{-1}\frac{h'-h}{k}\left(1-\frac{h'-h}{2\rho}-\frac{k^2}{12\rho^2}\right)* \quad (25)$$

$$\tfrac{1}{2}(Z'_0-Z_0)=90°+\tfrac{1}{2}C. \quad (26)$$

$$Z_0—Z=F \text{ and } Z'_0—Z'=F'$$

and finally $m = \frac{F}{C}$ and $m'=\frac{F'}{C}$

Struve,† Bauerfiend and others, have deduced rational formulæ for computing the coefficient of refraction from the observed temperature and barometric pressure, but such formulæ are of little utility, owing to the difficulty in the way of getting the temperature and pressure of the atmosphere.

§ 74. *Laws of Refraction.*—"Experience has proved that the refraction is greater and more variable at sunrise than at any other hour of the day; that it gradually diminishes in both respects, until 9 or 10 A. M.; that between those hours and 3½ P. M., it is comparatively stationary, and from 3½ P. M. to sunset, it increases in amount and variation, being the greatest during the night. The best period for observing, therefore, is between 9 A. M. and 3½ P. M., and the worst at sunrise and sunset."†

During the night, the refraction is less variable, but greater in amount, one about off-setting the other. A day with the sky wholly overcast is to be preferred to a clear or partially clear day.

"Although the refraction exhibits daily variations, and is a function of the temperature and the pressure of the atmosphere, yet it is extremely irregular; in its ordinary variations, the coefficient keeps within the range of $\frac{1}{9}$ to $\frac{1}{16}$, but occasionally and abnormally, it may be several times geater, or it may become zero, or even take a negative value. The refraction is slightly greater for lines crossing water, than for lines over land; it diminishes with altitude and with increasing temperature, but increases with increasing atmospheric pressure; in general its value depends upon the law of the distribution of temperature with the height."‡

There is an irregular effect of refraction, usually termed, "boiling," due to varying density of the atmosphere, which causes the target to vibrate rapidly through a small angle rarely exceeding 10″, but whose effect cannot be calculated.

For a table showing the diurnal variations of refraction, see U. S. C. & G. Report, 1876, pp. 361-2; also U. S. C. & G. Report, 1883, pp. 295 and 310.

§ 75. *Value of the Coefficient of Refraction.*

| | | |
|---|---|---|
| De Lambre, from observations in France | 0.07876 | —1 |
| Bégat's Traité de Geódésie, in France, for Summer | 0.06 | —2 |
| Bégat's Traité de Geódésie, in France, for Winter | 0.10 | —2 |
| Bégat's Traité de Geódésie, in France, for mean | 0.08 | —2 |
| Bessel, from operations in Prussia | 0.0685 | —3 |
| Gauss, " " " Prussia | 0.0653 | —3 |
| Struve, " " " Russia | 0.0618 | —3 |
| Corabœuf, " " " " | 0.0642 | —4 |
| Mean from all observations in France | 0.0665 | —3 |
| Chauvanet gives | 0.0784 | —1 |
| The British Ord. Survey | $.0.076x \pm$ 0.0035 | —6 |
| Do. for rays not crossing the sea | 0.0750 | —6 |
| " " " crossing " " | 0.0809 | —6 |
| U. S. C. S. in New England near the sea | 0.078 | —5 |
| U. S. C. S. in New England for small elevations | 0.075 | —5 |
| U. S. C. S. in New England between primary stations | 0.071 | —5 |
| U. S. C. S. in interior of country | 0.065 | —7 |
| U. S. Lake Survey in Central Illinois | 0.06 | —4 |

1. Chauvenet's Practical Astronomy, Vol. 1, p. 177.
2. Davies and Peck's Mathematical Dictionary, p. 20.
3. Ordnance Survey, p. 512.
4. U. S. Lake Survey Report, p. 428.
5. U. S. C. R. 1868.
6. Clarke's Geodesy, p. 283.
7. U. S. C. S. 1868, p. 62.

## Sec. 2. Trigonometrical Leveling.

§ 76. *By Observed Angle of Elevation.*—Let D, Fig. 10, represent the position of the observer, and E the station whose elevation is to be determined. Let A= the observed angle expressed in seconds of arc. $k$=the distance between the stations.

* U. S. C. & G. Report, 1882, p. 183.
† British Ordnance Survey, p. 214.
‡ U. S. C. S. Report.

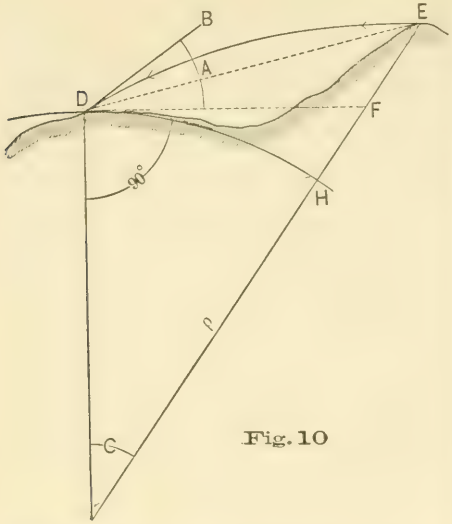



Fig. 10

"The difference of level, $dh$, is made up of HF, due to curvature, and FE, due to the angle of elevation. The angle of refraction $EDB = mC = m\frac{k}{\rho \text{ arc. } 1''}$. The true angle of elevation $EDF = A - \frac{km}{\rho \text{ arc. } 1''}$.

$$FE = k \tan.\left(A - \frac{mk}{\rho \text{ arc. } 1''}\right) =$$

$$k \tan. 1''\left(A - \frac{mk}{\rho \text{ arc. } 1''}\right)''$$

$$FH = \frac{K^2}{2\rho}.$$

$$\therefore dh = EH = FE \pm HF =$$

$$KA \tan 1'' - \frac{mk^2}{\rho} \pm \frac{K^2}{2\rho}. \quad (27)$$

The U. S. Coast Survey report for 1868, page 127, states in effect that the error produced by neglecting the term $\frac{mk^2}{\rho}$ is no greater than the uncertainty in the coefficient of refraction, and gives the following as being applicable for distances not exceeding 10 or 15 miles.

$$dh = 0.00000485\ kA \pm 0.0000000667\ k^2 \quad (28)$$

The neglected term is $0.1k^2$ ft. for $k$ in miles. If this term is not neglected

$$dh = 0.00000485\ KA - 0.0000001334\ mk^2 \pm 0.0000000667\ k^2 \quad (29)$$

The last term is plus for angles of elevation. The chief source of error in this as in all other formulæ for trigonometrical leveling, is the uncertainty in $m$.

§ 77. *By the observed zenith distance of the sea horizon.* Let Z=the measured zenith distance, $h$=the elevation sought. Then in Fig. 11

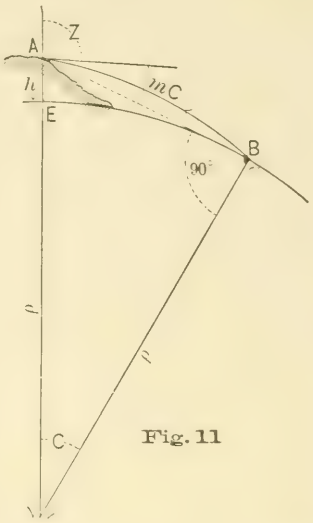



Fig. 11

$$\cos. C = \frac{\rho}{\rho + h}. \quad \text{Hence } h = \rho\frac{1 - \cos. C}{\cos. C}$$

$$= \frac{2\rho \sin.^2 \frac{1}{2} C}{\cos. C} = \frac{2\rho \sin. \frac{1}{2}C \sin. C}{2 \cos. \frac{1}{2}C \cos. C} =$$

$$\rho \tan. \tfrac{1}{2}C \tan. C.$$

Since C is always small, assume $\tan. \frac{1}{2}C = \frac{1}{2} \tan. C$, which, substituted above, gives,

$$h = \tfrac{1}{2}\rho \tan.^2 C.$$

To find C, notice that $Z + mC + (90 - C) = 180°$, therefore $C = \frac{Z - 90°}{1 - m}$, which, substituted in the above, gives

$$h = \tfrac{1}{2}\rho \tan.^2 \frac{Z - 90°}{1 - m} = \frac{\rho}{2(1-m)^2} \tan.^2(Z - 90)^* \quad (30)$$

§ 78. *By the zenith distance observed at one station.*—Let $dh$=the difference in level between the two stations. The triangle ADB Fig. 12, gives $dh = k\frac{\sin. BAD}{\sin. ABD}$

$$EAB = mC = FBA = m'C.$$

$$ABD = Z + mC - C$$

$$BAD = 90° - (Z + mC) + \tfrac{1}{2}C.$$

* U. S. C. S. Report, 1868, p. 127.

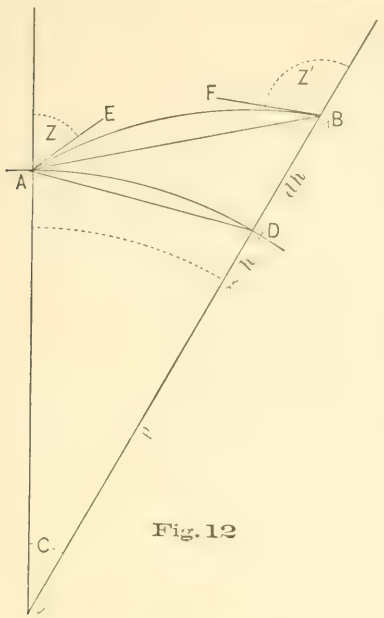



Fig. 12

$$dh = k\frac{\cos.(Z + mC - \frac{1}{2}C)}{\sin.(Z + mC - C)} \quad (31)$$

§ 79. *By reciprocal zenith distances to eliminate refraction.*—Let Z and Z′ be the measured zenith distances. Then the triangle ABD, Fig. 12, gives

$k$ : sin. ABD :: DB : sin. DAB.

Substituting for ABD and DAB their values in terms of Z′ and Z, assuming $mC = m'C$, and solving, gives

$$dh = DB = k\frac{\sin.\frac{1}{2}(Z' - Z)}{\cos.\frac{1}{2}(Z' - Z + C)}$$

§ 80. *Micrometrical Difference of Level.*—Another method is to measure by means of a micrometer inserted in the eye piece of the telescope, the difference in altitude between the different stations, the absolute elevations of one or more being known. The method of reducing the observations is easily understood.

§ 81. *Corrections.*—In the preceding it has been assumed that the instrument and the target observed upon, occupied what has been called the "station." The difference in height between the horizontal axis of the telescope and the trigonometrical point, or the ground at the station, and also the elevation of the target, should be measured and made a part of the record.

The correction to the zenith distance for the difference in height of the target and telescope above the ground may be computed by the formula—correction in seconds $= \frac{d}{k \sin. 1''}$, in which $d$ is the difference in height and $k$ is the distance between stations.

§ 82. *Limits of Precision.*—Reciprocal zenith distances measured at any two stations at the same moment of time, or under the same supposed condition of atmosphere, give the best results. When reciprocal, but not simultaneous, the observations should be made on different days, as in the case of horizontal angles, in order to obtain as far as possible a mean value of the difference between the respective angles and an average value of the refraction. The same care should be taken when the zenith distance is measured at one station only.

The condition of the atmosphere and the relative refraction may be so different at stations situated more than twenty miles apart, that, as a general rule, the difference of level determined even by reciprocal observations cannot be relied upon for the desired degree of accuracy at distances greater than about twenty miles, unless a very large number of measurements have been made, under the most favorable circumstances. Notice that the difference of height determined by trigonometrical leveling depends upon the coefficient multiplied by the square of the distance, and that, therefore, there is a limit to the distance for which any assumed mean coefficient can be depended upon for accurate results. The higher the elevations, the more reliable the results.

§ 83. In the final report of the U. S. Lake Survey (p. 544) it is stated that the probable error of determining a difference of level in Eastern Illinois by reciprocal zenith distances, using 8 to 10 separate measurements, made on 2 to 6 days, over lines 16 to 20 miles long, was somewhat less than 1 foot.

The U. S. C. & G. S. Report, 1876, p. 345, contains an account of trigonometrical leveling in California, over a line 14 miles long, in which the mean probable error of reciprocal zenith distances, 11 hourly observations on 5 successive days,

* U. S. C. S. Report, 1868, p. 126.
† U. S. C. S. Report, 1868, p. 125.

was 0.2 meters in 600 meters; for single zenith distances the error was 1.09 meters. The same volume contains an account of angular leveling in Georgia, in which, (p. 379), it is stated that the probable error per line of about 20 miles is .487 meters or $\frac{1}{68000}$ of the horizontal distance.

Probably the above may be considered as examples of the best work possible.

## Chapter V.

### Spirit Leveling.

§ 84. Spirit leveling may be divided into two divisions, viz:—ordinary leveling, or that undertaken, as a part of railroad surveys, drainage, &c.; and geodesic leveling, or that undertaken in connection with a triangulation survey, and in which extreme accuracy is sought. The latter is frequently called "precise leveling." The methods of the former are too well known to require discussion here; this chapter will be devoted exclusively to geodesic leveling.

### Geodesic Leveling.

#### Sec. 1. The Instrument.

§ 85. Spirit leveling instruments may be grouped in three classes. The first includes all instruments that can be adjusted by reversals, the wye (or Y) level being a representative of this class. The second includes all that cannot be adjusted by renewals of which the "dumpy" or English instrument is a type. The third includes all instruments whose errors of adjustment can be wholly eliminated by a system of double observations. The levels employed in geodesic leveling are of this class and are generally known as levels of precision.

There is considerable variety in the form of this class of levels, but only two have been used to any considerable extent in this country:—the Swiss or Kern level, by the Lake Survey and Mississippi River Commission, and a modification of the Vienna or Stampfer level, by the Coast and Geodetic Survey. The construction of the two are similar, hence only the latter will be described here. The former is described in the final report of the U. S. Lake Survey, p. 597, and described and illustrated in Jordon's Vermessungskunde, vol. II., p.

§ 86. *U. S. Coast Survey Level.*—The instrument is shown in Fig. 13.* The telescope may be reversed end for end and revolved about its optical axis, the two positions in which the horizontal thread is horizontal, being definitely fixed by projecting pins. The level can also be reversed end for end independent of the telescope. One end of the telescope and level can be raised and lowered by the micrometer screw. Near the micrometer is a cam hook, by which the weight of the superstructure can be raised off the micrometer during transportation. Under the telescope are two false wyes on lever arms by which the telescope can be raised out of the wyes for transportation. The whole instrument is secured to the tripod head by a brass plate which fits over the feet of the leveling screws.

The aperture of the telescope is 43 m m. ($1\frac{3}{4}$ inches nearly), focal length 410 m m. ($16\frac{1}{2}$ inches nearly), magnifying power 37. The value of one millimeter of the level scale is 1″.5 (1 inch=37″.5 or radius=800 feet.) The diaphragm is glass and has two horizontal and one vertical line ruled upon it. The two horizontal lines are used as stadia hairs to determine the length of sight.

A smaller size of this instrument is also used. The weight of the larger one, inclusive of tripod, is 45 lbs.; the smaller weighs 23 lbs.

§ 87. *The Rod.*—The rod used with this instrument was a target rod made of pine, 3″ by 1″, stiffened by a strip fastened along the middle of each face. One edge of the main strip has a self-reading graduation to cm. upon it. A brass strip, graduated to cm., is let into the side of the strip; it extends the whole length of the rod, being fastened immovably at the middle. Its temperature is determined by a thermometer let into the side of the wood. The target, which is moved by an endless chain, carries a short ivory scale, graduated to mm., which slides over the brass strip; the rod therefore reads to millimeters. The foot of the rod is a rounded piece of brass resting in a corresponding depression in the foot plate.† A handle and a disk level enable the rod man to keep the rod vertical.

§ 88. *Adjustments.*—The adjustments of this or other geodesic levels, do not

* From U. S. C. S. R., 1879, p. 202.

† Would it not be better if the end of the rod were hollowed out to fit a projection on the foot plate?

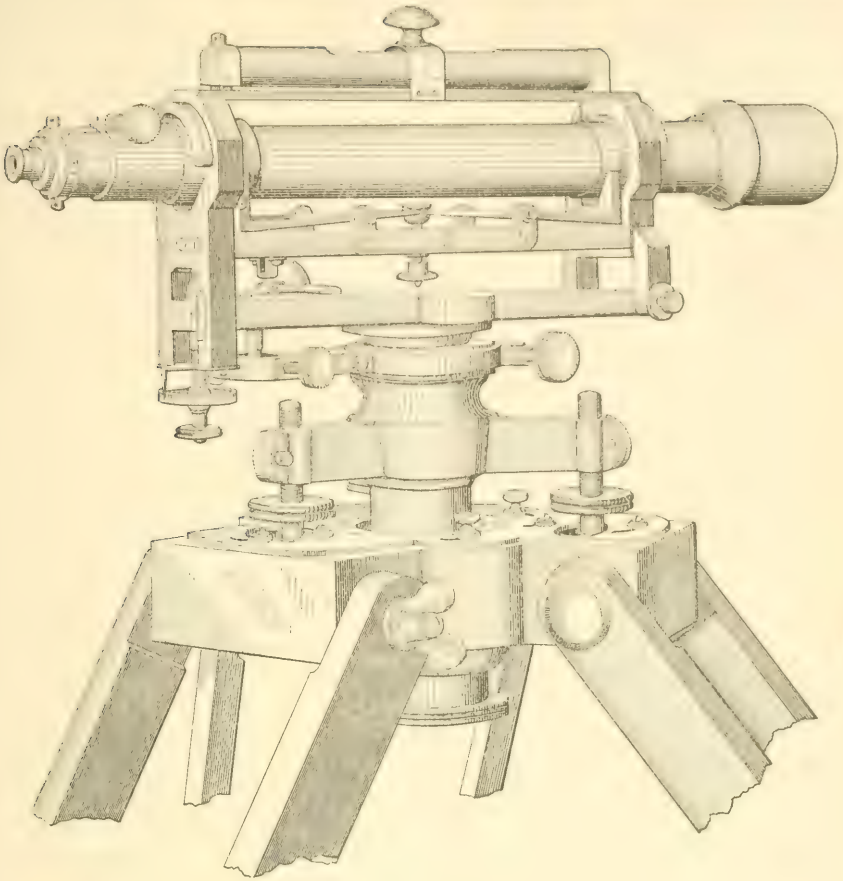


FIG. 13.

materially differ from those of the ordinary forms, and are generally more conveniently made. In the ordinary forms some of the less important adjustments are generally neglected as being less than the degree of accuracy aimed at, but in precise leveling, extreme accuracy is desired, and therefore every adjustment must be carefully attended to, even though it is the intention to use the instrument in such a manner as to eliminate all errors of adjustment. The usual method is to adjust the instrument as nearly as possible and then determine the error; each single observation can then be corrected, thus affording a check between the members of a double observation.

§ 89. Inequality of diameter of collars is the only error that cannot be eliminated by any system of double observations; it could be done if the line of the vertical axis were immovable; it is eliminated from the final result by equal back and foresights. But to employ the check of double leveling (as will be described presently), a correction for inequality must be appled to the rod reading.

The inequality of the collars can be determined by observations with a striding level, exactly as the pivots of an astronomical transit are examined; consequently it is unnecessary to describe the method here (see Chavenet's Practical Astronomy, vol. II. p. 153, or U.S.C. & G. S. Report, 1880, p. 210). The correction to be applied to the rod reading at the distance D, will be $d$ sin. 1″, in which $d$ is the pivot correction in seconds of arc.

§ 90. The absolute value, and the uniformity of the graduations of the rod, the

coefficient of expansion, the accuracy of the thermometer, and the disk level, should be tested carefully. The observer should also know his ordinary inaccuracy in performing the different parts of an observation.

§ 91. *Correction for Curvature and Refraction. Curvature.*—To compute the correction for curvature, let AD, Fig. 14, represent the line of apparent level;

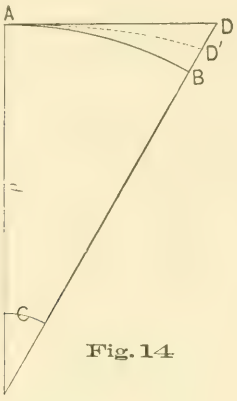



Fig. 14.

and AB the true level. DB is the correction for curvature. By Geometry $AD^2=DB(2BC+DB)$. Neglecting DB, as it is very small in comparison with 2BC, and representing the length of sight by $k$, and the radius of curvature by $\rho$, then correction for curvature

$$BD=\frac{k^2}{2\rho}$$

For BD in feet, and the distance in miles thus becomes

$$BD=0.667\ k^2$$

*Refraction.*—D′ is the true position of the target and D the apparent. It has been shown (Sec. 1, Chap. IV.) that the angle of refraction D′AD is equal to $m$C, in which $m$ is the coefficient of refraction and C the angle ACD.

$$C''=\frac{k}{\rho \sin. 1''}=k \tan. DAD'$$

$$=K\ DAD' \tan. 1''=\frac{mk^2}{\rho}$$

It will be impossible to select a value of $m$ which shall be true for all cases; but since the line of sight is always near the ground, and since the observations are generally made in the morning and evening, when the seeing is best, a large value should be chosen. The Coast Survey uses* $m=0.07$.

*Total Correction.*—The correction for curvature and refraction to be applied to the observed readings is

$$BD'=BD-DD'=(1-2\ m.)\frac{k^2}{2\rho}=\frac{.43k^2}{\rho}$$

$$=.000000020\ 45\ k^3$$

Numerous tables have been computed which give this correction directly for the different lengths of sight; or tables can be prepared which will give the difference of the correction with the difference in length of sight for an argument.†

For $k=210$ ft. the above correction $=.001$ ft.

For $k=1$ mile, the above correction $=0.57$ ft.

## Section 2. The Practice.

§ 92. *Method.*—There are two principal methods in leveling, according to the sequence of the instrument and rod, which may be called *single* and *double* leveling. Each may be performed with one rod or with two; this gives rise to four methods, which are represented graphically in Fig. 15. $I_1$, $I_2$, $I_3$, etc., indicate successive positions of the instrument; $A_1$, $A_2$, etc., successive positions of one rod; and $B_1$, $B_2$, etc., successive positions of the second rod.

I is the method of ordinary leveling, and may be called *single leveling with one rod.*

II is *single leveling with two rods.* By the use of the two rods, less time intervenes between the backsight and foresight; it is therefore more accurate, as there is not so much liability of change in the plane of the line of sight. It is also more rapid than with a single rod. This is the method used on the U. S. Lake Survey,‡ and the Mississippi River Surveys.§

III, *double observations with one rod* affords a perfect check against errors of adjustment and observation, since the difference in reading of the two foresights should be the same as the difference of the two backsights following.

IV, *double observations with two rods* combines all the advantages of II and III. It is the method used on the U. S. C. &

* U. S. C. S., 1882, p, 177.
† U. S. C. S., 1882, p. 178.
‡ Chief Engineer's Report, U. S. A., 1880, p. 2427.
§ Mississippi River Commission Report, 1881.

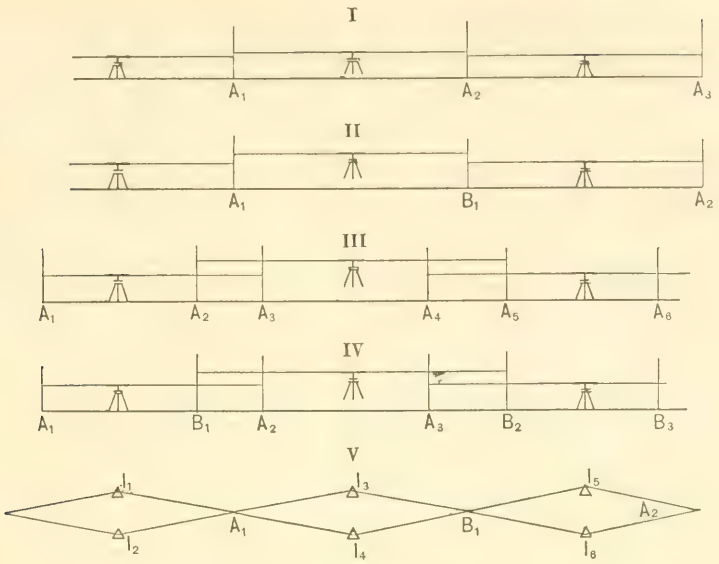



Fig. 15

G. Survey.* The numerals adjacent to the rods show the order in which they are sighted upon.

V is another method sometimes used. Two rods are used, being placed as in the figure. After having observed upon $A_1$ and $B_1$ the instrument is pulled up and reset a little to one side and the two rods sighted upon again. This method duplicates the work as far as instrumental errors are concerned, but is not an independent check.

§ 93. *The Observation.*—After having planted the tripod firmly and leveled the instrument, read both ends of the bubble, estimating the fraction of a division; next read the position of the two (or three) wires on the rod; then read the bubble again for a check to eliminate any change. Reverse the level end for end, and turn the telescope 180° about its optical axis, and repeat the operations as above. The first reversal eliminates any inequality in the lengths of legs of the striding level; the second eliminates any error of collimation. The mean of the several readings must be corrected for the difference in position of the bubble, and for inequality of the collars.

Instead of reversing the level and telescope at the same time, the observations are sometimes made as follows:—read upon the rod, reverse the level, and read again; reverse the telescope and read a third time, then reverse the level and make a fourth reading. The first method seems the better.

§ 94. If there is a milled head screw under one end of the telescope, the bubble can easily be brought to the middle each time; if there is not, it is better to bring it nearly to the middle and apply a correction. It is not enough to read only one end, since the bubble is liable to change its length with a change of position or temperature.

§ 95. On the coast survey, the method of observing differs slightly from that described above.* Errors of level and collimation are eliminated by reversing bubble and telescope on each backsight and foresight; but each observation is of a single wire on a target. The target is set but once for each station, the differential quantities being read by the micrometer under the eye end of the telescope. This seems not to be as good a method as the above; "there are two objections, aside from the time and labor required to set the target. First, there is no sufficient check against errors in reading the

* U. S. C. & G. Report, 1879, p. 206.

* U. S. C. & G. S. Report, 1879, p. 206.

positions of the target. Second, the micrometer is read for a central position of the bubble, the telescope is then moved to bisect the target and the screw read again, therefore there is no check on the stability of the instrument."

§ 96. *Length of Sight.*—On the U. S. C. & G. Survey, the length of sight ranges from 50 to 150 meters, according to condition of ground and weather, the average being 110 meters, the distance between the two rods on the same side of the instrument being 20 meters. On the Lake Survey,* the maximum was 100 meters; on the Prussian Land Survey, since 1879, it has not exceeded 50 meters, except for river crossings.†

The attempt is always made to place the instrument half way between the two stations; the rodman approximates the distance by stepping, and the instrument man measures it by the stadia hairs. On the Lake Survey, the difference between corresponding back and foresights was not allowed to exceed 10 meters.

§ 97. *Sources of Error.*—Probably in no other kind of instrumental engineering is it as important to distinguish between compensating and cumulative errors, as in leveling. For convenience in discussing them, we shall classify errors of leveling as follows: 1, Instrumental Errors; 2, Rod Errors; 3, Errors of Observation; and 4th, Personal Errors.

1. *Instrumental Errors.*—The principle instrumental error is due to the line of sight not being parellel to the level, which may be caused by imperfect adjustment, or unequal size of rings, or both. If the telescope slide is not straight, or does not fit snug, it will also produce an error. Of course the instrument must be focused so as to eliminate parallax. All of these errors are eliminated, whatever their value, by setting the instrument midway between the turning points.

It has been found that appreciable errors are caused by the settling of the instrument on its vertical axis, and of the settling of the tripod legs into the ground; in spongy or clayey ground the tripod legs are sometimes gradually lifted up. These errors, though small in themselves, are more important than is generally supposed, inasmuch as they are cumulative; but probably they would be appreciable only in precise leveling. They can be eliminated by running the line in the opposite direction.

A small source of error arises from the fact that the adhesion of the liquid to the sides of the glass tube prevents the bubble from coming precisely to its true point of equilibrium. Even though it may finally arrive at the true point, it is liable to be read before it has stopped moving. Consequently a tube should contain considerable liquid, so as to give mass sufficient to overcome the adhesion.

Another small error is the effect of the sun in raising one end of the telescope by the unequal expansion of the different parts of the instrument. In ordinary leveling operations, the bubble is first brought to the middle and then the target is sighted in, leaving an interval for the sun to act. The error is greatest in working toward or from the sun. It is cumulative; for, on the backsight, one wye is expanded, which elevates the line of sight; while on the foresight the other wye is expanded, which depresses the line of sight, the two errors affecting the difference of elevation in the same way. The error on the foresight is farther increased by the cooling of the wye which was expanded during the backsight. The error due to the sun is always small, and can be nearly eliminated by noticing the position of the bubble after setting the target, and can be still further reduced by shading the instrument. The Indian Geodetic Survey proved conclusively that the error was appreciable, even when the instrument was shaded.*

2. *Rod Errors.*—The principal rod error is in not holding the rod vertical; this may be remedied by attaching a level or by waving the rod. In waving the rod, care must be taken that the front face is not lifted by resting upon the back edge when the rod is revolved backward.

With telescoping target rods when extended, the slipping of the upper piece, after the target has been pronounced correct and before the vernier has been read, is a source of error. The target itself may slip, but this is not so probable, because of its less weight.

* Final Report, p. 598.
† Wright's Adjustment of Observations, p. 375.

* Jackson's Aid to Survey Practice, p. 181.

Another source of error is the settling of the turning point, due, in course or sandy soil, to its own weight, or to the impact of setting the rod upon it. The resulting error is cumulative. The remedy in the first case is to use a long peg, or to rest the rod upon a triangular plate with the corners turned down slightly, or with spikes on the under side. This foot-plate with a convex button attached, on which to place the rod, is better than a peg for all cases. Whatever the turning point, the rod should never be dropped upon it.

Finally, another small rod error is the error in the graduated length. This affects only the total difference of elevation between the two points. This is a much more important source of error with the numerous home-made self-reading rods now in use, than with the rods make by regular instrument makers.

"An important source of error in spirit leveling, and one very commonly overlooked, is the change in the length of the leveling rod from variations of temperature. It is quite possible that errors from this source may largely exceed the errors arising from the leveling itself."*

3. *Errors of Observations.*—The principal error of observation is in reading the position of the bubble; even if the bubble is kept in the middle, it is nevertheless read. Every leveler should know the error on the rod corresponding to a given difference of reading of the bubble; he then knows how accurately he must read the bubble for a given degree of accuracy in the results.

Another source of error is the moving of the bubble after being read, and before the sighting has been made. This movement of the bubble may be caused by its being read before it has come to rest, by disturbing the instrument by stepping near the tripod legs, by turning the instrument slightly in azimuth, or by raising or lowering one end of the telescope in focusing, or by the action of the sun or wind. The bubble should be re-read after the target is nearly adjusted, or with a self-reading rod, after the reading has been made and before the rodman is signaled to move on. These two probably constitute the chief sources of error in leveling operations.

If the reading is made on either side of the vertical hair, there is a possibility of error, owing to the horizontal hair not being horizontal; with Y levels, not provided with a means of preventing the rotation of the telescope in the Y's, this possibility becomes a probability. Any device which insures the horizontality of of the horizontal hair increases the rapidity and accuracy of the work.

The inaccuracy of telling when the hair exactly covers the center of the target is a source of slight error, but not so small as many think. Owing to this source of error, the difference in accuracy between a target-rod and a self-reading rod is not so great as their difference in precision. Because a target is read to thousandths is no evidence that it is accurate to that limit. In precise leveling, self-reading rods are generally used; to reduce the error of reading the position of the hair upon the rod, two or three horizontal hairs are used, a reading being taken for each of them and the mean used as the rod reading. For a single observation, a target rod is more accurate than a self-reading one; but three observations as above are probably more accurate than a single observation upon a target, and can be made in about the same time.

When very long sights are required to be taken with the level, another source of error must be considered, viz., the curvature of the earth and refraction. Owing to these two causes, a point 225 feet distant appears about 0.001 ft. too high; this error increases as the square of the distance. It is wholly eliminated if the instrument is always exactly half-way between the turning points. Refraction is not always the same; its mean effect was used in finding the above correction. Consequently, if there is abnormal refraction or a change of refraction between sights, or a tremulousness or "boiling" of the air, small errors may result. The only remedy is to shorten the length of sight, or wait for better atmospheric conditions. The atmosphere is usually in the best condition for seeing just before sunrise and a little while before sunset, although the refraction is then greater. A cloudy day is better than a clear one.

There is a possibility of error in recording the observations and making the computations, but in precise leveling there are so many checks that there is no

* Wright's Adjustments of Observations, p. 372.

probability for serious error in this respect.

4. *Personal Errors.*—The errors previously described are liable to occur with any observer; they are due chiefly to the instruments and to the nature of the work, and would probably not materially differ for equally skilled observers. We come now to a class of errors which depend mainly upon inaccuracies peculiar to the individual.

With a target rod, errors of one foot and one-tenth are not uncommon. The only check is for the rodman and observer to read it independently and compare notes; but this is inconvenient and not always possible. With a self-reading rod this error is less liable to occur, especially if three hairs are read.

Finally, each individual has errors peculiar to himself, or to the work he is doing. One may read a target higher or lower than another of equal skill; or one observer in reading the position of the bubble may have peculiar views as to what constitutes the end of the bubble, or he may habitually read the bubble so as to get a distorted view of it through the glass tube; errors from these causes are compensating. Again, the target may be better illuminated on foresights than backsights, as in working toward or from the sun; in this case the error will be cumulative.

With skillful observers, all such errors are quite small and generally cancel themselves. In fact, the errors here classed as personal are possible rather than demonstrated as actually occurring; and yet, there is nothing more certain than that in any series of accurate observations, there is a difference between the results of different individuals. This difference is known as "personal equation." In long lines of accurate leveling, it has been found that each man's way of performing each operation has a decided effect upon the final result.

§ 98. It is a curious fact, but one abundantly verified, that when lines are duplicated in opposite directions, the discrepancies tend to one sign and increase with the distance. This subject has been much discussed and various reasons assigned, as settling of instrument, settling of turning point, dis-leveling effect of the sun, illumination of the target, and personal bias in reading the target or bubble (but these should cancel in back and foresights), but none of the reasons are entirely satisfactory. "These discrepancies vary with different observers and are not even constant for the same observer, are nearly proportional to the distance, and seem to be independent of the nature of the ground, the direction in which the work is done, the season, or the manner of supporting the rod.*

The accuracy is increased by leveling alternate sections in the opposite direction, as is done in India. It may be still urther increased by reading the backsight first at each alternate time the instrument is set up.

The effect of this class of errors may be eliminated by each observer duplicating this work in the opposite direction under as nearly the same conditions as possible.

§ 99. *Limits of Precision.*—The probable error per unit of distance is generally adopted as a convenient measure of the precision reached. According to the theory of probabilities, the final error of a series of observations, affected only by accidental errors, will vary as the square root of the number of observations; hence the error of leveling a number of units of distance is assumed to vary as the square root of the distance.

This assumption would be true if accidental errors were the only ones made, and if the number of observations were strictly proportional to the distance leveled, *i.e.*, if the length of sight were constant; but in the preceding article it was shown that leveling is affected by an error which is nearly proportional to the distance. It has frequently been noticed that, considered individually, the errors of a number of short lines were well within the limits which were prescribed to vary as the square of the distance, yet when the sum for several lines were considered the total discrepancy would exceed the limit. In other words, for a line leveled in only one direction, the error is not strictly proportional to the square root of the distance. One part of the error is proportional to the square root of the distance and another portion varies nearly as the distance. Hence, the shorter the distance, the easier to attain a limit prescribed to vary as the square root of the distance.

* Chief Engineer's Report, 1884, p. 2555.

"According to the Geodetic Association of Europe, levels of precision executed of late years in Europe, show that the probable error of a line of levels of precision should never exceed

5 mm. $\sqrt{\text{distance in kilometers.}}$

(0.021 ft. $\sqrt{\text{miles}}$),

that 3 mm. $\sqrt{\text{distance in kilometer}}$ is tolerable, 2 mm. $\sqrt{\text{dist. in Km.}}$ is a fair average, and 1 mm. $\sqrt{\text{dist. per Km.}}$ is high precision."* The Coast Survey requires 5 mm. $\sqrt{2 \text{ dist. in Km.}}$, (0.030 ft. $\sqrt{\text{miles}}$). Of late years the Coast Survey's and Mississippi River Survey's work are considerably within the limit of 2 mm. $\sqrt{\text{Kilom.}}$ The Mississippi River Commission's limit is $5\sqrt{\text{Kilom.}}$ (0.021 ft. $\sqrt{\text{miles}}$. "The limit on the British Ordnance Survey is 0.01 ft. per mile."

Results of leveling are often given of apparently greater accuracy than the limit above; but regularity of result and evenness of error is of more importance than occasionally small disagreement. It is usually the latter that is recorded.

If the error was determined by duplicating the work in the same direction, and especially if at the same time, as by methods III, IV, or V, the difference will be the apparent error, and necessarily be too small. The result obtained by the adjustment of a net of lines by the method of least squares affords the best method of arriving at the degree of precision.

§ 106. *Speed.*—The amount of work that an observer should do in a day cannot be stated definitely; it depends upon the accuracy to be obtained, the power and delicacy of the instrument, the method pursued, the ground, and very largely upon the weather. For the very best work, even in clear weather, not more than 3 or 4 hours can be utilized. The average daily run for several seasons on the Mississippi River, using a Kern level and method II (§ 93) was a trifle over a mile per day for the entire season, and a little over a mile and a half for the days on which work was done.* On the Lake Survey, with the same instrument and method, the distance was about two miles per day for the days on which leveling was done.

* U. S. C. S., 1882, p. 522.

* Chief Engineer's Report, 1884, p. 2462.

# COMPRESSED GUN COTTON FOR MILITARY USE, WITH SPECIAL REFERENCE TO GUN COTTON SHELLS.

By MAX V. FÖRSTER, Premier-Lieutenant a. D., Technical Superintendent of the Gun Cotton Factory of Wolff & Co., Walsrode, Berlin, 1886.

Translated, with the Author's permission, by JOHN P. WISSER, First-Lieutenant 1st Artillery, U. S. Army.

## II.

### Paraffining Gun Cotton.

1. *Paraffining Dry Gun Cotton so that the Paraffine penetrates the piece and takes the place of the water, which is always present in wet Gun Cotton.*

Wet gun cotton, in store, will dry in time unless it be packed air-tight, and must therefore be moistened from time to time.

To save this labor, it has been proposed to replace wet gun cotton by paraffined dry, on the ground that paraffine does not evaporate.

This would be a very practical suggestion if the paraffine were capable of replacing the water. But this is by no means the case; paraffined gun cotton is rather a substance intermediate between wet and dry, without the good properties of either.

The principal advantage of wet gun cotton, containing 25 per cent. of water, is, it is not combustible. This property deprives it, in handling, storing and transportation, of the character of an explosive, and it is a great advantage to be able to store gun cotton in this condi-

tion, especially when large quantities are on hand.

This will come into play, particularly in case fire breaks out in the magazine or in its vicinity; even if the supply of gun cotton is destroyed, as will be the case if large quantities of other combustible substances are present, and the flame is therefore very persistent, danger there cannot be.

Although spontaneous decomposition is not absolutely impossible, yet wet gun cotton will have the preference over all other explosives formed by the nitration of organic substances, which are all combustible, in that spontaneous combustion, at all events, cannot take place.

The property of incombustibility is that which above all renders wet gun cotton particularly suitable for military use, and especially in submarine mines, since, in this case, large quantities of the explosive will be accumulated in one place, and, in case large quantities of explosive burn, there is great danger arising from this very fact; moreover, by the gradual rise in temperature an explosion may even take place.

Paraffined gun cotton, however, is not incombustible; in fact, any little flame will set fire to it, and it will burn almost as rapidly as dry gun cotton.

The rapidity with which the flame spreads and develops is the true criterion of the degree of danger, which may result from its combustion, to a magazine filled with explosive.

As a further test of paraffined gun cotton, the following experiment, made at the factory at Walsrode, may serve:

Pieces of gun cotton, not thoroughly freed from acid, were paraffined. After a period of two years the gun cotton showed signs of decomposition, green flecks and curdy spots began to appear, the mass became soft and liquid; the appearances were the same as in the case of poor, dry, unparaffined gun cotton. In case of wet gun cotton this phenomenon was not observed.

But not only does the paraffining not prevent decomposition, it must, according to all appearances, induce a spontaneous decomposition. Paraffined gun cotton was prepared by drying wet gun cotton and digesting it in a bath of paraffine at 65° C until the entire piece was permeated by the paraffine. This requires from ½ to one hour, according to the size of the pieces. If the paraffine bath is at a lower temperature, a longer time will be required.

This process may injure the gun cotton every time.

It is a determined fact that at temperatures of +65° C. nitrous acid is evolved from gun cotton; it is detected by means of the reaction with potassium iodide and starch paper. The paraffine causes this nitrous acid, as well as that which may be evolved in the course of the year, during the storage of the gun cotton, to be retained. In case of dry or wet gun cotton, not inclosed air-tight, the gases developed can escape.

The discovery has often been verified in the factory at Walsrode that, according to the potassium iodide and starch test, gun cotton of slight stability, which is permitted to give off its vapors freely, becomes more stable after a number of years. The acid developed partly combines with the chalk and partly volatilizes, so that a more stable gun cotton remains. Very slight traces of nitrous acid are evolved from all gun cotton, even at comparatively low temperatures. If gun cotton be digested in warm water, or for a longer time in cold water, nitrous acid may be detected in the water by the addition of sulphuric acid and zinc iodide and starch solution.

We made the following experiment:

Gun cotton was washed at the laboratory until the wash water no longer gave any reaction for nitrous acid; then the gun cotton was left in the drying oven at +30°C. for eight days and again washed. The washings again gave the reaction for nitrous acid.

The same experiment, repeated with the same gun cotton, invariably gave the same result.

Hence, we must conclude that all gun cotton contains nitrous acid.

Moreover, all commercial nitre, as used in the manufacture of gunpowder, contains nitrous acid.

We applied to one of the most celebrated factories of chemicals for fused nitre, free from nitrous acid, and were told that they had not succeeded in preparing it.

We then prepared it in our own laboratory, by careful fusion and refusion, under certain required condi-

tions, and preserved it in a well-closed glass flask.

When examined after an interval of several months, the nitre again contained nitrous acid.

Professor Himly, of Kiel, often expressed himself to the author to the effect that: "All nitro compounds are unstable, all organic substances are easily decomposed, only inorganic substances should be used for explosives." True as this is theoretically, it is nevertheless not verified in practice.

In all cases, however, it will be well, even with gun cotton, not only to exercise great care in the manufacture, but also not to rely too much on its safety in preparing charges for blasting, as is too often done.

We call attention, moreover, to the fact that, when the nitrous acid has combined with the chalk to form calcium nitrite, as long as no more is evolved than the chalk can combine with, it cannot injure the gun cotton. Nevertheless, it again makes its appearance when tested with solution of potassium iodide and starch, or zinc iodide and starch, because the calcium nitrite is dissolved by the water in which the gun cotton is digested; and when sulphuric acid is added the nitrous acid is liberated and detected by the reagent. A gun cotton may therefore be free from acid, and yet, when tested, give the reaction for nitrous acid. From all this we conclude that it is useless to attempt to prepare gun cotton free from nitrous acid. But such gun cotton is not to be confounded with that which contains considerable quantities of free acid, even nitric acid. Such gun cotton, instead of improving with time, will deteriorate and rapidly decompose.

Any indication that gun cotton, even only moderately free from acid, but chemically altered, decomposes with the production of light, we have never observed.

Returning to paraffined gun cutton, we do not mean to state that a good gun cotton must necessarily decompose to such an extent as to be dangerous, but only that it is better to avoid the process of paraffining, if possible; furthermore, we do not say in general that it is injurious to preserve a good gun cotton air-tight, but rather have frequently verified the fact that a good gun cotton, stored air-tight for years, has lost nothing of its permanence, as determined by the potassium iodide and starch test; we simply believe that for all gun cotton it is better, if practicable, to store it without inclosing it air-tight.

If we return now to the physical properties of paraffined gun cotton, we shall see that its only similarity to wet gun cotton is in being less sensitive to a shock than dry, on account of which property paraffining has been mainly advocated; it is, however, much more sensitive to a shock, and especially to ignition by a shock, than gun cotton with 15 per cent. water.

In this connection we made the following experiment:

Shots were fired at short distances from the Mauser Infantry arm against disks of gun cotton 15 cm. in diameter and 5 cm. thick. Gun cotton with 15 per cent. water stood three hits; paraffined gun cotton was ignited the third hit.

The shocks to which the gun cotton designed for use in submarine mines is liable, even dry gun cotton can endure; for that purpose it will not, therefore, be necessary to paraffine the gun cotton. The charges of the Fish torpedo are an exception, as they are often exposed to the enemy's fire, but for this very reason paraffined gun cotton cannot be used.

Having shown that paraffined gun cotton is too sensitive to shock, it should be stated, on the other hand, that it has lost the power of being detonated by the detonation of a primer containing 1 grm. mercuric fulminate. It can be detonated only by means of dry gun cotton.

As paraffine does not evaporate it forever prevents the use of gun cotton permeated with it for priming cartridges, while wet gun cotton need only be dried to be used for this purpose.

*We repeat, therefore, that, in our opinion, paraffined gun cotton is not an advantageous form of the explosive.*

In the work "The Modern High Explosives" of Manuel Eissler, Mining Engineer, New York, 1885, gun cotton is very unjustly dealt with, as it is stated there that in England, experiments had been made showing that gun cotton is so sensitive to a shock, that in a system

of submarine mines charged with gun cotton, the explosion of one mine caused the neighboring ones, and thus successively the entire series, to explode, and that it would therefore be easy, by means of a countermine, to explode an entire system of mines charged with gun cotton, and thus render it harmless.

It is a well-known fact that there is no navy in Europe which does not use compressed gun cotton almost exclusively for charging submarine mines, except in so far as old powder mines are still on hand, and just because it is so little sensitive to shock.

In describing the chemical properties and the investigations of gun cotton, Mr. Eissler has also shown that he does not understand its character and properties.

2. *Paraffining dry gun cotton externally, so that the paraffine penetrates several millimeters, and forms with the gun cotton a coating, which protects the inner dry portion of the cartridge against external action, especially of moisture.*

The operation is especially adapted for the preparation of priming cartridges. The opening for the reception of the primer is closed with a sheet of paper before the cartridge is dipped in the paraffine, and the cartridge is thus protected against moisture in general during years of storage.

An improvement of the process consists in coating the walls of the cavity which serves for the reception of the primer, by means of acetic ether. The cartridge is thereby rendered impervious to water for a considerable time, even after the sheet of paper is broken, and the primer is placed in position, preparatory to using the cartridge, even under water.

The detonating power of the cartridge is not diminished by the thin coating of dissolved gun cotton; it will detonate even under water, in spite of the fact that water penetrates between the primer and the walls of the cartridge.

In the case of charges for submarine mines, however, the use of paraffine offers no advantages. However carefully the paraffining is performed, it is not possible to ascertain whether the paraffine may not have penetrated too far into the cartridge; it is possible that the cartridge has lost the power of being detonated by the primer, but we are not able to determine this with certainty. Moreover, cartridges paraffined in this way will, according to our experience, become cracked, thus allowing moisture to penetrate. The piece of gun cotton is not an unalterable mass; it changes its form with changes of temperature and with changes in the hygrometric state of the atmosphere; hence, small cracks will be formed, and in time large ones, too.

These possibilities will be ground sufficient for not applying paraffine in any manner to cartridges used in submarine mines. These cartridges must be preserved against moisture by the mode of packing, during storage and use.

We add, in this connection, that cartridges which are air-dried, and are preserved in a dry and airy magazine, will be detonated at all seasons, in every kind of weather, by a 1 grm. primer; it is therefore not necessary to take such extreme precautions with it, provided only that good 1 grm. primers are used.

3. *Paraffining Wet Gun Cotton.*

Pieces of gun cotton, with 25 per cent. water, may be coated externally with a layer of paraffine several millimeters thick, but the paraffine cannot penetrate on account of the presence of the water.

At ordinary temperatures the layer of paraffine is tolerably firm and prevents the piece from drying, to a certain extent, and gives it a tolerably permanent form.

By changes of temperature, and by frost, innumerable cracks are rapidly formed, however, and portions begin to crumble, causing the two advantages just mentioned to be rendered nugatory.

According to experiments made at the factory at Walsrode, it appears that of the most carefully-prepared wet pieces of gun cotton, paraffined externally, several withstood the effects of the first winter, none the second; the crevices became so numerous that there was no longer any impediment to the evaporation of the water, and the form of the piece of gun cotton was no more permanent than in pieces without the layer of paraffine.

Not unimportant is the fact that the layer of paraffine increases the size of the pieces, and a given space will therefore contain less gun cotton.

In the case of pieces of gun cotton, 140

c.c. in volume, the increased space required amounts to 12 per cent., and, besides, 12 per cent. paraffine, *i.e.*, a considerable weight of a substance, which, together with the wood of the packing boxes, forms a combustible material, penetrates into the wet gun cotton.

Small pieces will evidently not be very suitable for this process.

If the layer of paraffine be less than 2 mm. thick, it will not subserve its purpose even for a short time. In conclusion, it will be exceedingly difficult and expensive to paraffine a large quantity of wet gun cotton, externally, so that the pieces are well coated with paraffine, and that the layer of paraffine will not diminish the facility with which the wet gun cotton may be detonated.

By experiment it was found that the detonation of wet, externally paraffined pieces of gun cotton was not effected by a priming cartridge of 150 grm., when the pieces are not in contact, but separated 10 mm. from each other. In case of charges not inclosed, failures to explode, or partial explosions, may easily take place.

*The result is that we must also regard wet, externally paraffined gun cotton, on account of its increased cost and disadvantages, as not advantageous.*

### Coating Gun Cotton by Immersing it in a Solvent.

This process has proved a success in the experiments, extending over three years, and conducted in every possible direction. The coating lasts well, cracks or peelings occur only to an inconsiderable extent. A portion of wet gun cotton thus coated was preserved in well-closed cases, another portion in open cases under water. Although a few pieces contained cracks, the form and density of the pieces, obtained by pressure in the manufacture, was preserved. The time, during which the moisture is retained by the gun cotton varies mainly with the mode of packing it; impermeable the coating is not, but still it protects in a great degree as well against the penetration of water in the case of dry gun cotton as against the evaporation of it in wet. The principal advantage lies in its rendering the pieces as tough as wood, and whoever has had occasion to observe the condition of even well-pressed and well-packed gun cotton, after transportation over long distances, will appreciate this advantage.

Moreover, the coating prevents the formation of mould, although in the case of wet gun cotton the formation of mould is favored by the very mode of storing it, and goes on in spite of the fact that the gun cotton is enclosed, as when it begins on the sides of the packing chests and extends to all the material stored in the chests, in which case the pieces of gun cotton cannot remain free from it, whether coated or not. Are they coated, however, the mould will not penetrate the pieces, but remains outside on the coating. It may easily be removed by wiping the pieces. It cannot therefore injure either the structure or the composition of the gun cotton.

We will remark, in this connection, that when wet gun cotton, on which mould has formed, is placed in an airy store-room, in which it can dry, the growth of the fungus is stopped. Moreover, we moistened gun cotton, which seemed to be especially threatened with the formation of mould, on account of the climate or the mode of storage, with carbolic acid, with good effect.

The coating will commend itself more especially in the case of gun cotton intended for use in submarine mines or the Fish torpedoes, which must endure transportation and always a long term of storage, and which may possibly have to endure unpacking and repacking in the vessels used for holding it in the mines.

The coating is also suitable for the gun cotton used for explosion by the land forces, and which, in the event of war, must endure long-continued transportation, and often unpacking and repacking.

In case of granulated gun cotton, intended as a charge for shells, the coating is indispensable. All granulated powder will jolt in the shell when fired, friction on the walls of the shell is unavoidable, and thereby ignition of the powder and premature explosion of the shell may be produced.

In case of granulated gun cotton this is true in a higher degree than ordinarily.

We therefore fill up the interstices in the granulated gun cotton, with which the shell is charged, with liquid paraffine,

which forms of the entire filling, after solidification, a compact, no longer compressible, body, excluding the possibility of a jolting of the charge or a movement of the separate parts.

The coating of the separate grains prevents the paraffine, while liquid, from penetrating into them, and it is necessary to prevent this, because grains of gun cotton permeated with paraffine require a priming cartridge so large that it cannot be conveniently applied or cannot be applied at all.

Every granulated gun cotton is particularly subject to conversion into dust; the coating prevents this, and it is thereby made capable of being transported and of being used in warfare.

The facility of detonation, in case of coated gun cotton, is in no wise diminished; dry gun cotton remains subject to detonation by a primer to the same degree, and wet gun cotton to the detonation of the dry and the adjacent wet gun cotton.

Nor can there be any ground for the opposite view, since no foreign body is carried into the gun cotton or added to it by the coating; a very small portion of the piece of gun cotton on the surface, about as thick as a sheet of thin paper, is simply dissolved by the solvent, and remains, after the evaporation of the solvent, as a thin, closely-adhering pellicle. This pellicle consists of dry gun cotton, and it has therefore been said that the process of coating by means of acetic ether renders wet gun cotton combustible.

Occasionally, too, the word "ether" has led to the belief that, after the completion of the fabrication of the coating, combustible vapors of ether may remain.

The latter is of course not at all the case. The ether used for solution evaporates very rapidly, and the above-mentioned hard, dry pellicle remains. The amount of dry gun cotton thus produced is, however, exceedingly small; in a prism 230 c.c. in volume it amounts to 1 grm., and in case of one of 140 c.c. it is still smaller; therefore less than $\frac{1}{2}$ per cent.

A chest containing 50 kg. of wet gun cotton will therefore contain $\frac{1}{4}$ kg. of dry gun cotton, a quantity involving no danger whatever, and which, in comparison with other combustible material present in the storage of wet gun cotton, is insignificant.

Gun cotton is generally packed in wooden chests, pitched inside. The wood of the chest weighs 15 kg., the tar $\frac{1}{4}$ kg. per 50 kg. of packed gun cotton—an amount of combustible material sufficient to produce a continuous heat, in case a fire breaks out in the magazine, adequate to vaporize gradually the water of the wet gun cotton, and thus convert it into dry gun cotton.

The $\frac{1}{2}$ per cent. of dry gun cotton produced by the coating, will not alter these relations, since it does not fly about in the form of dust and come in contact with any light that may be carried about and thus take fire, as it is in a compact, not a pulverulent form, on wet gun cotton, combined with the latter in chests.

As already stated, we are of the opinion that keeping gun cotton moist prevents all danger in case of fire in the magazine, as it prevents a rapid development of the fire; we are, however, also of the opinion that, in all ordinary methods of packing or arrangement of the magazine, the stock of gun cotton may be considerably damaged by fire, and, in case of inadequate arrangements for extinguishing fire, may even be entirely destroyed, and any change in the wet gun cotton, such as the coating produced by acetic ether, which is insignificant in effect, will not alter the character of wet gun cotton in this respect.

The coated gun cotton long retains the odor of acetic ether. After some time, however, not a trace of the odor remains an indication that all the acetic ether has evaporated. No alteration in the gun cotton or in the pellicle is produced, however. We have found that no acetic acid is formed either in the pellicle, or immediately under it, or in the piece of gun cotton itself.

Should traces of acetic acid, formed by the mixture of vapors of acetic ether with atmospheric air, accumulate, however, due to the inclosing of freshly-coated gun cotton, no injury will result, as it is in no way injurious to gun cotton.

The process of coating gun cotton by dipping it in acetic ether is called "gelatinizing" gun cotton, and this expression is often used in the text.

### Gun Cotton Shells.

It is well known that the effect of shells filled with ordinary gunpowder against stone arches, against iron coverings, against armored walls and armored turrets, is often very slight, and that attempts have been made for some time to introduce a more energetic explosive as a charge for shells. Compressed gun cotton must be recognized as best adapted for this purpose, as it belongs to the most energetic of the explosives now known, exists in the solid form, is convenient to handle, safe in transportation and storage, little sensitive to shock (not at all when wet), chemically stable even after long-continued storage, and has been known in the military world for 20 years, and is in use at present giving good results.

From these considerations we have endeavored to apply compressed gun cotton to produce an increased effect in the explosion of shells, and we have succeeded, by extensive firings and explosions at the factory at Walsrode, in discovering a method of filling the shells which promises to fulfill all the requirements, in that it not only renders possible the firing of the ordinary rifle shell for mortars or guns without exploding in the bore, but also insures the explosion of the shell at the target.

This filling of the shell—the gun cotton as well as the primer—endures all the shocks produced by the expanding gases in the bore of the gun; there is no danger whatever that one of the two portions of the filling of the shell will explode prematurely by the shock received, and thus produce an explosion in the bore.

We have proved this by the following experiments:

1. By firing a considerable number of shots (over 200) with gun cotton shells with full charges, from an 8.8 cm. gun, with an initial velocity of 450 m.;

By firing from the rifled 15 cm. mortar, with an initial velocity of 200 m.;

By firing from a rifled long 15 cm. gun, with an initial velocity of 400, but in the case of the two last named guns with the 6-caliber steel shells as well as with the ordinary shells.

2. By firing shots with ordinary shells, in which separate parts of the filling were left, the others being omitted, so that every part might be tested separately against various objects.

Besides the immediate practical result, namely, that the shells were fired without exploding in the bore, it was computed in these experiments that the shock experienced by the shell with a high final velocity, in striking a solid object, was very much greater than that which it receives from the expansive powder gases in the bore of the gun. If it can, therefore, endure the former without exploding (*i. e.*, when the plunger, which is to cause the explosion of the shell on striking, is removed), even without separate parts of the charge or of the fuse being changed in form or position, it may be assumed with perfect certainty that it will endure the latter shock in the bore of the gun under all circumstances, and that, even when the plunger is in the fuse, explosions in the bore will not take place, as the plunger is the same as that which has been in use for some time in fuses and found perfectly safe. Besides the plunger, the fuse contains the primer, necessary for the detonation of the gun cotton. In the construction of this primer, which plays a most important part in the experiments with gun cotton shells, we have modified somewhat the form ordinarily used and rendered it particularly safe, and, as shown by the experiments, we have thoroughly tested it under all kinds of circumstances. Besides the primer described in our patent, we used another form, which guarantees all that is possibly required. After a combination of wet and dry gun cotton has been accepted as a charge for shells, the remainder of the question is simply one of a proper fuse, which we found extremely difficult to answer, but believe now to have thoroughly and completely solved.*

* In filling the shell a hollow space is left in the prolongation of the fuse-hole for the priming cartridge, in which is temporarily placed a hollow cylinder. After the paraffine congeals the cylinder is withdrawn and replaced by a tube of thin sheet brass. The diameter of the priming cartridge is the same as that of the fuse-hole. A diameter of 15 mm. and a length of cartridge of 42 mm. give it a weight of 7 grm., which is sufficient for the detonation of the charge. The priming cartridge is provided with a channel 8 mm. in width and 82 mm. deep.

The fuse is a percussion fuse, modified. The case of the fuse is lengthened and the end closed by a screw. In the hollow space, formed in lengthening it, is lodged the primer cap, containing 1 grm. mercuric fulminate. The plunger remains as before. The primer is provided with a strong case, surrounded by an india-rubber cap, to weaken the shocks transmitted to the primer. The primer projects nearly 22 mm.

The experiments, which determined the capability of the charge of our shells to resist the effects of shocks, were as follows:

*a.* We fired charged shells, from which the plunger, which we consider as having no part in the experiments, had been removed, but which contained the rest of the fuse and the charge of gun cotton, against objects of great resistance at short distances.* The shells reached the object with a high final velocity, 420 m.

The targets were earth walls, walls of strong wood, and wooden walls covered with wrought iron rails.

We found that our gun cotton shells endured the greatest striking force against these objects in the highest degree, without exploding, so long as the plunger was left out.

We increased the strength of the wrought iron rails, against which we fired, as much as the strength of the shells would permit, and found as a result that, as long as empty shells were not broken by the striking force, the shells containing gun cotton and primer remained intact also. When the shell breaks on striking the iron, and the parts of the charge, in pressing forward, are brought in direct contact with the iron, producing great friction, the gun cotton generally burns and the primer detonates.

Nevertheless, many cases arose in which the shell broke, and the pieces were found 1 meter deep in the wall of the earth behind the rail, without any combustion or detonation of the charge having taken place.

*b.* Against the same objects we fired shells, which were provided only with the gun cotton charge, or only with the fuse, without the plunger, but with the primer.

The first lot of shells we opened by placing on them a gun cotton cartridge and detonating it; in case the charge of the shells did not also detonate, we were able to show that the separate grains of the charge of gun cotton suffered no compression, but were found perfectly intact, and that no jamming of the charge—either towards the base or towards the head of the shell—had taken place; everything had remained in place.

The last lot of shells, those in which the fuse and primer were present, we filled with peas instead of gun cotton, and with a wet priming cartridge; we opened them after the firing by cutting off the base with a boring machine, and were able to show that the primer had not been detonated.

We fired from the 8.8 cm. gun shells of the ordinary form, but made of steel, under the same circumstances as above described, and obtained very good results, but before making the results public we desire to continue the experiments.

While the experiments with partially charged shells showed that our filling is very safe against shock, the experiments with completely charged shells have shown that the arrangement of the primer functions very well, and that the charge of gun cotton always detonates entirely and with full effect. Partial explosions of the gun cotton charge did not occur in using granulated gun cotton.

The form in which we prefer to use the gun cotton for the charges of our shells is different from the disks of gun cotton heretofore in use.

A shell, filled with gun cotton in the form of disks, is described fully in the work of Lieutenant General Brialmont, "La Fortification du temps présent."

The disk form of gun cotton is not advantageous for the filling of shells, because the shells must be provided with a base or head, screwing off and on, so that the shell may be filled. We therefore prepare the charge of gun cotton not only in the form of disks, but also in the form of grains, so that the filling may take place through the mouth of the shell.

Each separate grain of this "gun cotton powder" has a specific gravity of over 1. The gravimetric density of the gun cotton powder is 0.7; 700 grm. (dry weight) will therefore fill a space of 1,000 c.c.

The grains are rectangular, 8 to 12 mm. in diameter in cross-section, and either cubical or elongated. They are gelatinized, or coated by dipping in acetic ether, and have thereby acquired a compact form, and are prevented from crumbling to dust.

from the fuse, and this projection enters the channel in the priming cartridge.

In the other form of primer used the fuse was not altered, the primer being separate therefrom, and is protected from shocks by means of india-rubber.

* We removed the plunger, because we used percussion fuses, which, if the plunger had been in place, would have caused the primer to detonate on striking.

After the grains are poured into the shell, the latter is filled with melted paraffine, which, after solidifying, converts the whole filling into a solid mass.

In filling the larger shells we use wet grains as the principal part of the charge, adding at the end about 200 grm. dry grains, so as to entirely fill the shell.

In the use of powder of nitrated cellulose as a charge for shells, in the case of most of the different kinds of powder, partial explosions will probably frequently occur, and combustion or the carrying away of a part of the charge will often take place.

Gun cotton and other forms of nitrated cellulose are as a rule more difficult to detonate than is generally supposed.

We made the following experiments:

In a strong wooden chest, lined with tin, we placed uncompressed gun cotton containing 30 per cent. water, and pressed it as compactly as was possible without the use of machinery; the chest had an interior capacity of $\frac{1}{4}$ cubic meter and held 50 kg. gun cotton, dry weight.

A piece of compressed gun cotton, 500 grm. in weight, was placed in this chest, in the center of the wet, uncompressed gun cotton and detonated; the chest and its contents were burst asunder, without causing either a partial explosion or a combustion of the loose gun cotton.

A pile of such gun cotton was placed on the ground, and a piece of compressed gun cotton, 250 grm. in weight, placed on it and detonated; no explosion of the loose gun cotton took place, although it could not avoid the shock of the cartridge.

We must therefore regard loose, wet gun cotton as not belonging to the explosives. In one of its forms, as "collodion cotton," it is transported by the railroads at ordinary rates, and no danger will result to commerce, if compressed, wet gun cotton—which, so far as its properties in this regard are concerned, is nothing else than collodion cotton, although in its use as an explosive it is more advantageous—is transported by rail under the same privileges as collodion cotton. In order to make possible the fulfillment of the requirements, the amount of water now prescribed for collodion cotton must be reduced for compressed gun cotton to 25 per cent., as the latter cannot absorb 50 per cent. water.

Gun cotton with 25 per cent. water is a substance which cannot be exploded by any accidents possible on a railroad.

During the storage at the place where the gun cotton is to be used, the cartridges will dry of their own accord, and can then be detonated with a primer.

It will thus be possible to furnish the smaller purchasers with a suitable sudden explosive, and farmers, for instance, would be greatly benefited thereby, since a sudden explosive may be used with advantage, to blow up rocks and stumps of trees, in the construction of roads and in clearing land.

Uncompressed gun cotton in the dry state burns rapidly, explodes even, but does not detonate, and can, therefore, as is well known, be used as gunpowder. The same is true of gun cotton powder. It offers, of course, no great resistance to the shock of the priming cartridge, nor does one portion of the powder to another. Gun cotton, itself easily detonated, if it be not in large, heavy pieces, but in small, light ones, will move aside from the shock of the detonated priming cartridge, and will be blown away or only slightly burned.

The finer the powder, the smaller and lighter the grain, the more is it subject to partial explosions and combustion, and the larger must be the priming cartridge, and the greater the degree of confinement of the charge, to produce perfect detonation.

It is very probable that most forms of granulated powder, composed of nitrocellulose in large masses, cannot be brought by practicable means to complete detonation.

The gun cotton manufactured by us at the Walsrode factory behaves differently. In the first place, the grains are not too porous and light, they have the same constitution as the large pieces of pressed gun cotton; in the second place, the grains are not too small, 6 mm. cube is the very smallest size, and we give them even, for reasons connected simply with the manufacture, the greatest possible size, *e. g.*, about 10x10 mm. in cross-section, 25 mm. in length.

In the third place, and this is very important, the paraffine, used to fill up the interstices in the shell, forms with the

grains a compact mass, which acts as a whole exactly like a piece of compressed gun cotton.

In general a 1 grm. primer is sufficient for the detonation of this mass, when the grains are completely dry; are they wet or entirely paraffined, a priming cartridge of corresponding weight must be inserted.

While in the case of wet grains formed into a compact mass by inclosing them in the shell and filling up with paraffine, a priming cartridge 35 grm. in weight is sufficient; grains entirely paraffined, as we have seen, require a much heavier and larger priming cartridge; indeed, so large that it can hardly be applied in a shell. In case a 65 grm. priming cartridge is not sufficient, one of 100 grm., although it may produce detonation once in the experiments described, will not always do so with certainty, and combustion and partial detonations will be unavoidable in case of paraffined grains. Moreover, paraffining increases the size of the grains and diminishes, therefore, their gravimetric density.

These reasons, in connection with the decreased chemical stability, render grains entirely paraffined in every way disadvantageous.

In the case of the dry and the wet grains used by us, coated and formed into a solid mass by means of paraffine, a partial detonation never occurs, even when the charge is but very lightly inclosed, *e. g.*, in a box of thin tin, as shown by our previously described experiments, and as must be evident from the nature of the case.

It is unavoidable by using grains that the weight of the charge is somewhat less than when disks of the same specific gravity as the grains are used, but our experiments have shown that the difference in effect of the two kinds of gun cotton is not great.

On the other hand, the filling of shells with granulated powder carries with it the advantage of much greater strength in shells made in one piece over shells composed of two parts, or, in case strength of shell is not particularly required, the possibility of making the walls of a steel shell thinner, or of making the shells of cast iron, even if not six calibers long, at least longer than ordinary shells, since cast iron always furnishes a sufficiently strong material for shells made in one piece. In this way a shell will be obtained especially effective and at the same time cheap, the only means of insuring the employment of gun cotton for shells to the greatest, and, as it appears to us, judging from its limited use, necessary extent.

Granulated gun cotton has, furthermore, the valuable property of supplying a material proper for all kinds of shells, no matter of what caliber or kind. Granulated gun cotton can be used in all sorts of shells.

The advantage offered by this universal explosive, as compared with gun cotton disks, which require for every kind of shell a different size, need not be dwelt upon; the effort to obtain ammunition of general application is sufficiently well known and regarded as indispensable.

Moreover, granulated gun cotton will permit the supply of steel and cast iron shells now on hand, which were designed for charging with gunpowder, to be converted into gun cotton shells, and thus give them not only a higher explosive power, but also so increase the number of pieces resulting from the explosion, that their effect must be exceptionally great.

The number of pieces resulting from the explosion of artillery projectiles has been increased, as is well known, by forming the interior core of the shell of many parts, which are held together by the outer wall of the shell, and also by constructing shrapnel; the former method can be used in but few kinds of shells, and therefore an increase in the number of pieces resulting from explosion, in the case of most of the ordinary shells now on hand, is greatly to be desired. The second method for obtaining a large number of pieces by the explosion, the use of shrapnel, has the disadvantage of requiring a number of special kinds of projectiles, and it is well known that we would gladly give them up if a good substitute could be obtained in some form of shell.

The cast iron shell, filled with granulated gun cotton, offers, in this respect, great advantages, at least for the ammunition of fortification and siege guns, for it is not to be expected that gun cotton shells will be introduced in field artillery.

The following experiments present some idea of the number of fragments obtainable in the explosion of ordinary shells.

We exploded the shells in a space, specially constructed for the experiments, well closed, built of masonry and covered on the inside with boards, but containing an exit for the gases resulting from the detonation, to diminish the explosive force, and obtained:

From a cast-iron 8.8 cm. shell, weighing 7 kg., filled with ordinary gunpowder,
37 fragments, weighing in toto 6,160 grm.
Filled with granulated gun cotton,
200 fragments, each weighing over 10 grm.
600 " weighing from 1 to 10 grm.
From an 8.8 cm. steel shell weighing 6,640 grm., filled with granulated gun cotton,
23 fragments, weighing in toto 2,260 grm.
127 " " " 2 865 "
150 " " " 5,125 "
From a cast-iron 15 cm. shell, weighing 27 kg., filled with ordinary gunpowder,
42 fragments.
Filled with granulated gun cotton,
376 fragments, each weighing over 10 grm.
828 " weighing from 1 to 10 grm.

A large part of the cast-iron shell is broken into very small fragments. Pieces less than 1 grm. in weight have not been considered in our estimation, although they are entitled to consideration, as most of them received from the explosive charge alone so much energy that they penetrated boards 25 mm. thick, and, evidently, in actual practice against troops, some effect would still be produced by them. As regards fragments over 10 grm. in weight, which have sufficient energy for proper effect even at considerable distances, the charge of granulated gun cotton was nine times as effective as the charge of gunpowder—certainly a remarkable result.

Moreover, gun cotton shells, unless provided with a slow fuse to delay explosion, possess the special property of bursting immediately after the first impact, not after an appreciable time, as is the case with gunpowder shells.

We made the following experiments in this connection:

*a.* Two targets made of boards 40 mm. thick were placed, one behind the other, $\frac{1}{3}$ m. apart. A gun cotton shell penetrates the first target and bursts between this and the second.

*b.* A target of boards, 4 square meters in area, was fired at with an 8.8 cm. cast-iron shell, in such a way that the shell struck the ground 2 m. in front of the target. The shell burst before reaching the target, which was penetrated by 135 fragments.

*c.* Two targets, as above described, but separated by 2 m., were fired at by an 8.8 cm. powder shell so as to strike the center of the targets.

The shell pierced both targets and burst only in rear of the second in an earth wall.

The powder shell had the same percussion fuse as the gun cotton shell; the later bursting of the former cannot therefore be due to the fuse, as heretofore always assumed, but to the slower development of the powder gases of the charge, as compared to the gun cotton gases.

The property of gun cotton shells of bursting in this way at the first moment of impact, must give them, in a variety of cases, many advantages over gunpowder shells, *e. g.*, in the destruction of objects into which the shell cannot penetrate, such as heavy armor or solid masonry, when the shell strikes obliquely, in which case it will be deflected if charged with gunpowder and have no explosive effect, and also in case of objects which are so easily penetrated that the gunpowder shell will burst too late and generally behind them, such as gun-carriages, caissons and other wagon material.

By inserting a slow-burning composition in the fuse, by which the primer is detonated some time after the shock of striking, or by means of a time fuse, the bursting of the gun cotton shell may be delayed for any length of time. This delay will be necessary in the case of the bombardment of fortifications protected by an earth covering, in order that the latter may be penetrated before the shell bursts.

From data obtained at the cast-steel works of Friedr. Krupp, relating to experiments with guns and projectiles, we quote the following, as they appear to us to indicate in what cases a gun cotton shell may be of use.

*Gun*: 15 cm. gun, 35 calibers long.

*Projectiles*:

| Kind. | Length of Projectiles. | | Total weight, (including charge) kg. | Charge. kg. |
|---|---|---|---|---|
| | mm | calibers | | |
| Steel armor shell..... | 500 | 3.35 | 51 | 1.5 |
| Cast-iron ordinary shell. | 596 | 4 | 51 | 3.4 |
| Cast-steel ordinary shell. | 670 | 4.5 | 51 | 6.2 |

Mortars are used for purposes other than those for which guns are designed, and the projectiles should be constructed with this difference in application in view. In general, the walls of the mortar projectiles may be much thinner than those of the projectiles used in guns, since the pressures of the gases in the bores of the respective pieces are as 1 : 2. Mortars are used exclusively for firing with great elevations.

They are intended:

1. To remove earthworks.

2. To fire on troops posted behind cover.

3. To destroy coverings.

1. In order *to remove earthworks* shells are required which penetrate as deep as possible before bursting, which hold a large charge and which possess the requisite strength, so that the powder may be consumed as completely as possible before the beginning of the explosive effect.

High elevations and percussion fuses, the action of which is delayed, must be employed. Cast-iron shells are less suitable for this purpose, as they must necessarily have thick walls, and can therefore contain only comparatively small bursting charges, and offer, besides, too little resistance to the gases of the charge, so that the bursting takes place before all the powder is consumed. Steel shells are much more effective in this case, because they are free from these objections.

If it be not desired to fire with full charges in the piece the walls of the steel shell may be made very thin. To obtain the normal total weight, the length may be increased. In this way we arrive at shells with great bursting charges, the so-called torpedo shells.

2. *To fire on troops behind cover* shrapnel are used.

3. *Destruction of coverings.* While in firing on earthworks, it is necessary to delay the action of the percussion fuse, in order to obtain great penetration before explosion, in firing on coverings it is desirable to have the explosion take place instantly after striking, because otherwise the projectile will burst in ascending arc, and the effect of explosion for the purpose sought will be lost. As is well known, it has not been possible to overcome this difficulty. This object can hardly be attained in a satisfactory manner, because, even with the most delicate fuse, a certain amount of time elapses and must necessarily elapse, between the striking and and the bursting of the shell.

We deduce from these data the following:

The armor shells are capable of containing only a small charge, and the effect of even the largest calibered steel armor shells, with an initial volocity of 500 m. and more, obtained by the use of brown powder, will not be very greatly increased by ever so energetic a bursting charge, but still it will be increased, and at least clear out the opening produced by the shell.

The cast-iron and cast-steel shells contain a sufficiently large charge to produce the requisite effect.

The torpedo shell is the form most suitable for the application of gun cotton.

To remove earthworks the gun cotton shell is valuable, as its effect in earth is greater than that of the gunpowder shell. A delay in the action of the fuse is easily obtained.

To break down coverings the gun cotton shell is essential, as it alone can attain the object sought, namely, the condition that the shell must burst in striking; the gunpowder shell can never attain this object, since its bursting after striking must be ascribed, not to the fuse, but as first shown in our experiments,* to the gunpowder charge.

Even the cast-iron shells will be considerably improved by the gun cotton charge, since the slight resistance which they offer is not detrimental, and the thick walls, and consequent smaller charge, is not such a great disadvantage,

* Experiments *a*, *b* and *c*, a few pages preceding.

considering the much greater energy of gun cotton.

But a steel shell with thin walls is always to be preferred.

As regards shrapnel, we remark that they may perhaps be entirely superseded by the cast-iron gun cotton shell, since the latter, as our experiments have shown, gives as great a number of pieces by explosion as shrapnel.

We repeat that the ordinary cast-iron 15 cm. shell, filled with granulated gun cotton, gave

376 fragments, each over 10 grm. in weight.
823 " between 1 and 10 grm. in weight.

We hope that Mr. Fried. Krupp with the extensive means at his disposal in his establishment, will soon begin experiments with gun cotton shells, since it is evident that they are capable of at least supplying many very delicate wants in the effects of explosives. If they can offer advantages on account of a difference in the trajectory at the target, as we have seen to be the case in discussing their property of bursting instantly on striking, the question of obtaining a more energetic charge for shells than gunpowder is of the greatest importance, even if not in the same degree for all kinds of projectiles, and this question must come up for solution in the near future.

Should Mr. Krupp undertake the experiments, we are convinced that he will solve this, as he has all other questions relating to artillery that have come under his notice, in a brilliant manner, and if we, with our gun cotton factory, with our knowledge of explosives and of gun cotton in particular, derived from years of experience, can be of any service, we are always at his disposal.

Interesting cases, in which gun cotton shells may be used, are found in Major Schumann's work on armored gun carriages, in which it is stated:

"In England was adopted a method of armoring for sea-coast fortifications according to the so-called Sandwich system, a combination of 3 to 5 plates, generally 15 to 16 cm. thick each, with layers of wood between.

With the latest steel shells, which have been so greatly improved, it is to be expected that the penetration into the different layers will be sufficient to cause them, if charged with sudden explosives, to act with disastrous effect on the entire system.

The penetration of projectiles in massive forged iron armor, 40 to 60 cm. thick, will evidently be much less. There is, however, in case the plates are very soft, and therefore little inclined to crack, a not unimportant increase of effect to be expected from charges of sudden explosives, at least in case of those shots which strike near the edges of the plates.

The two latest improvements in projectiles join hands here.

The Krupp shells, which are made of excellent material and forged under the hammer over a mandrel, receive such a degree of toughness by this method of manufacture that they are stronger than solid shot. Their hardness is increased to such a degree that a projectile from the 15 cm. gun, 35 calibers long in the bore, for instance, penetrated two plates, each 18 cm. thick with a layer of wood, 25 cm. thick, between, and showed but a single slight alteration, in that the point was abraded about 1 mm.

The second improvement consists in the use of sudden explosives in charging the shells, the hardness and strength of which allow them to penetrate sufficiently deep in vertical, soft forged iron plates, to make use of at least a part of the explosive effect of sudden explosives. In cases, therefore, where such armor plates can be struck with velocities which admit of the sufficiently deep penetration of such projectiles in soft forged iron, to allow sudden explosives to act with effect, means will have to be devised to prevent this penetration.

Examples of armor plates which may be struck directly are:

*a.* Armored ships.

*b.* Armored sea-coast fortifications.

*c.* Armored turrets in land fortifications.

The Schumann method of construction consists in preventing direct impact on the armor of land fortifications, with armor shells fired from long guns, by building the turret in the form of an umbrella, the armor plate of which the shells cannot strike in a direction perpendicular to the surface. They will strike at an acute angle and glance off

without effect. The effect of explosion can be the only one that can act, but this will be too late, as the shell bursts too late, whether it be a gunpowder or a gun cotton shell."

From these constructions of Major Schumann it appears that he expects important results from the use of sudden explosives as a charge for armor shells, and we add, in reference to the technical construction, the following:

In case gun cotton, as a charge for armor shells, which therefore penetrate into the armor, detonates directly from the shock of the shell in striking the armor plate, and this without fuse and without primer—we do not doubt that the dry priming cartridge will partially burn or explode, the only question is, will it detonate in such a way as to cause the wet gun cotton to detonate at the same time? —then it will detonate before the shell has exerted its full energy, hence too soon. The development of the detonation of gun cotton as compared to that of gunpowder is, as we observed, instantaneous, and this will be true whether it is caused by the primer or by the shock.

A fuse, even a slow one, in projectiles which strike armor plate perpendicularly and penetrate into it, will break, hence no effect can be expected from delaying the bursting by making the fuse a slow one.

In case dry gun cotton is detonated by the shock, the bursting of the shell will take place too early; in case it does not detonate, but only takes fire and undergoes partial combustion, it would be possible—by arranging the primer in the shell so that it is not detonated too early by the shock in the bore of the gun and cause bursting in the bore—to delay the bursting of the shell, and the events taking place in the shell would succeed each other as follows:

The primer would be detonated by the burning dry gun cotton, and cause that part of the dry gun cotton which is not yet consumed to detonate.

Similar relations may be obtained by placing a primer in a piece of dry gun cotton, provided with a recess for the purpose, and igniting the piece of gun cotton at any point. In a large number of experiments, which we personally conducted, the gun cotton was always caused to detonate after ignition, and by the combustion in conjunction with the primer.

In shells we found the action similar.

We believe, moreover, that, by a special construction and application of the primer, it will be more difficult to cause it to detonate than to cause dry gun cotton to burn.

On the other hand, there is no danger whatever that, when the dry gun cotton begins to burn, the shell will burst before the primer is detonated.

It is therefore quite possible to make an armor shell, containing wet and dry gun cotton and a primer, but without a fuse, burst at the proper time, hence not too early, since the development of the flame of dry gun cotton and the transmission of the flame to the primer will require a certain amount of time.

We do not know whether this has been determined by experiments, but it is clear that in case of shells which do not penetrate into the armor plate, and are not designed to, the relations are much more favorable. These shells would be provided with as great a charge as possible, and with a fuse, of course not a slow one.

The shell will either strike the armor plate at an acute angle and glance off—in which case it will burst, contrary to the view of Major Schumann, quite close to the armor plate—or it will strike perpendicularly, so that it will be crushed or flattened, and thus in all cases be detonated, and at the proper time for the charge to act with full effect, since it bursts immediately after impact.

We believe, too, that the Schumann armored constructions are not safe against the effect of gun cotton shells as they are against gunpowder shells, and that therefore gun cotton shells will be of service against all kinds of armored constructions.

We return to the object of our experiments with gun cotton shells, viz., that, in opposition to the propositions to use a dynamite cartridge, thrown by means of compressed air from the bore of a gun, and in opposition to many other propositions, and the application of apparatus already on hand, to throw projectiles filled with sudden explosives, in all of which uncommon, complex and very expensive apparatus, difficult to transport, is required, we propose to fire at great

ranges the ordinary shell as a gun cotton shell, specially provided with our mode of arrangement, from ordinary guns and mortars, with the gunpowder charges now in use. We lay particular stress on the simplicity of the application of our gun cotton shells, and, according to our view, we must add that, under all circumstances, at least on land, nothing should ever be used as a moving force for projectiles but the most compendious and cheapest source of such power—gunpowder.

Our constructions relate only to the filling of the shells now in use with gun cotton; no change of material other than the charge of the shell takes place; even the weight of the filled shell remains unchanged.

These results we have obtained:

1. By the manufacture of a special, new and effective granulated gun cotton.

2. By means of a special arrangement for filling the shells, viz., by filling out the interstices with paraffine.

3. By the construction of a suitable primer.

We are convinced that the gun cotton shell will be of great service, even if it will not accomplish wonders.

The effect of sudden explosives is overrated; on a small part of a heavy armored plate, for instance, one cannot obtain nearly the same effect with ever so energetic a sudden explosive as may be obtained with a steel shell from a 30 cm. or 40 cm. gun, but in the first place there are but few such guns, and in the second place they cannot be moved about on land. On land and in the attack and defense of fortifications the limit of producing increase in effect by increasing the caliber is soon reached, and nothing remains but to increase the effect of explosion, and we believe that shells containing sudden explosives will play an important part in the future, although they will not accomplish all that is expected by those who overrate the possibilities in the case; but just because these shells will not work wonders, we are of opinion that the sudden explosives must be applied so as not to alter the artillery material.

We submit these lines to the indulgent reader with the assurance that, although we have said much *pro domo,* we have also endeavored to carry out the experiments without prejudice and to draw the conclusions in the same spirit.

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## SOURCES OF POWER.

From "The Engineer."

In the older treatises on mechanics we find the sources of power classified under the heads, "Wind, Water, Steam, Animals;" and, broadly speaking, these are still the only sources of power we possess. But when we deal more in detail with the subject, we find that wind in all probability owes its capacity for performing work to the sun, while water is absolutely inert, save as actuated by gravity, and steam is of course merely an agent by which heat is converted into work. Concerning the methods by which animals perform work we are entirely ignorant, no physiologist having as yet succeeded in tracing the sequence of processes by which food is converted into mechanical energy. Enough is known, however, to show that the process has nothing in common with that by which work is performed by heat engines. So that the analogy sometimes drawn between a man and a machine must be rejected as far-fetched, permissible to the poet, indeed, but not to the philosopher. Furthermore, it is known that the work got out of food by men and animals is much greater on the whole than can be obtained from fuel consumed in the best steam engines. That is to say, a man or a horse may be more economical sources of energy, in one sense, than any machine. Be this as it may, it is sufficiently evident that we depend for the performance of all the work done in the world on two main sources of power—heat and vital energy. The action of gravity, it is true, causes the falling of water, and so gives out power; but the water has to be raised before it can fall, and this raising is

effected by the heat of the sun, which evaporates moisture and so indirectly gives us clouds and rain.

It appears to be not unreasonable that men should ask themselves now and then if there are no other sources from which power may be derived—is there no other force of nature that can be made the slave of man? The question has been put in hundreds of ways, and remains unanswered. The seekers after motive power have been nearly as numerous and persistent as those who wasted their lives in search of the philosopher's stone. With the "perpetual motion" man we have no patience, and it is perhaps scarcely necessary to point out to our readers that we are about to speak of something very different indeed from the ordinary notion of perpetual motion. Inventors who have sought that have, for the most part, attempted to get something out of nothing; that is, in a word, create energy. There is a wide difference, however—a great gulf, indeed—between this and an attempt to still further explore nature's secrets in search of a source of energy—that is to say, of work—now unavailable. Now, in dealing with this question of sources of energy, it seems to be not impossible that a misapprehension of the nature and bearing of the laws of the conservation of energy may do a great deal of harm. It may be said, for example, that it is quite useless to search for a source of energy which can be better or more economical than what we have now, and much more to the same effect. But let us ask ourselves what is this law of the conservation of energy, on what is it based, and what would be the consequences to the universe if it did not exist? Such questions are very seldom asked, because the number of men who are at the pains to think for themselves is small. But when they are asked, the answer is remarkable. There is really no reason at all why energy should be conserved, and so far as our senses supply evidence, far from being conserved it is being profusely wasted every day. Of course, if we go a little behind the evidence of our senses, we find that the waste is only apparent, not real. It is much easier, however, to form an idea of a universe in which the law of the conservation of energy has no existence, than it is to realize a fourth dimension in space, or even the life of the inhabitants of Flatland. As a help to the realization of such a universe, we may point to the fact that the sun has been giving out energy for millions of years, and that there is no reason whatever to think that he has lost any portion of his original heat. In other words, it is simply impossible to prove that what we call energy is not created in the sun. Again, let us take gravity. We have here the most stupendous force in nature. There is no reason to imagine that it is capable of degradation. If all the planets fell into the sun, gravity would of necessity have performed an enormous amount of work; but no one can say that after it was done gravity would be any the weaker. It may indeed be said that the law of the conservation of energy has only just missed being disproved, if the words "conservation of energy" be used in one sense. So far as can be seen there is no reason why the line of magnetic force should not behave like lines of electrical force or heat force, and admit of being intercepted or stopped. It would then suffice to put a permanent magnet under one end of a beam, the other end of which should be connected in the usual way with a crank and flywheel. Then, by interposing and withdrawing a thin intercepting plate at the proper intervals, we should have a machine which would work steadily until it was worn out, without the expenditure of one farthing for fuel. In the popular sense of the word, we should create power; and the perpetual motion men would spend their lives in patenting details, while the principle would be public property. Has any one the least idea why magnetic force lines should traverse every known material? Can any one assert that if this was not the case the existence of the universe would be impossible or even difficult? Can anyone assert with certainty that no means will ever be found for intercepting or dissipating magnetic rays, without expending energy in doing so? Finally, is it not possible to obtain some idea of the cause of magnetic force from this very peculiarity of its behavior? To put an extreme case, it may be urged that the law of the conservation of energy being true, it is impossible to intercept a magnetic force line. What then is the nature of the

force which will comply with this condition? On the other hand, it is possible to intercept a heat, light, or electrical line, and yet the law of the conservation of energy is not interfered with—*ergo*, magnetic force must possess features which distinguish it from the other forces we have named; from all other forces, indeed, save gravity. One deduction seems to be consistent with facts—namely, that magnetism and gravity are original or primal forces, and that the remaining forces—such as light, heat, and electricity—are derived, built-up, or composite forces. That, in a word, gravity and magnetism are elements, while light, heat and electricity are compounds. We speak of light, heat and electricity as "forces;" perhaps it would be more strictly correct to speak of them as manifestations of force. But what we have written will serve sufficiently well to convey our meaning.

The sum and substance of what we desire to convey is that there is nothing known which renders it absolutely certain that mankind may not yet find new sources of energy in nature. No one can assert positively that it must always be impossible to make electricity work for us. If a man had shown Socrates a lump of coal and told him that it could be converted into work he would have laughed at him. Our purpose will be served in writing this article if we make our readers understand that there is as yet at least no finality in science. There is no reason, for example, to conclude that it is absolutely and physically impossible that sources of power may yet be discovered which are not now dreamed of. The electricity which now rends the forest oak, or brings down the lofty edifice in a hideous ruin, may yet be taught to light our towns. Chemical science may give us new reactions which will supply large sources of power. The world does not yet know everything; and he who knows most is least likely to assert dogmatically that things which do not exist now never can exist in time to come.

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# THERMODYNAMICS.

By DE VOLSON WOOD, C. E., M.A.

Written for Van Nostrand's Engineering Magazine.

1. *To find the difference between the specific heats of a substance graphically.*

Let $K_v$ be the specific heat of a substance in foot-pounds at the absolute temperature $\tau$ for volume constant, and $K_p$ the specific heat for pressure constant at the same temperature. Draw two isothermals corresponding to $\tau$ and $\tau_2$ indefinitely near each other, such that $\tau_2 - \tau = \triangle\tau$, and from any point $a$ in the isothermal $\tau$ draw $ac$ parallel to the axis of $x$ and $ab$ perpendicular thereto; also the adiabatics $am_1$, $bm_2$, $cm_3$; then will the heat absorbed for the path of the fluid $ab$ be

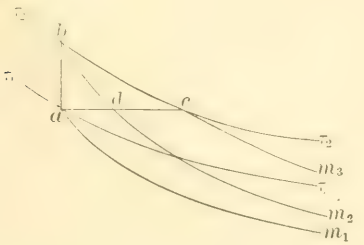



Fig. 36

$$m_1abm_2 = K_v \cdot \triangle\tau,$$

and the heat necessary to raise the temperature $\triangle\tau$ along the path $ac$, the pressure being constant, will be:

$$m_1acm_3 = K_p \cdot \triangle\tau,$$

the *ultimate* values of which will be

$$m_1abm_2 = K_v d\tau,$$
$$m_1acm_3 = K_p d\tau;$$
$$\therefore m_2bcm_3 = (K_p - K_v)d\tau.$$

But $m_2bcm_3$ is the heat absorbed at constant temperature during the expan-

sion from $b$ to $c$, which was found to be, in a preceding article, page 268,

$$m_2 bcm_3 = \tau \frac{dp}{d\tau} dv,$$

which, compared with the preceding equation, gives

$$K_p - K_v = \tau \left(\frac{dp}{d\tau}\right) \left(\frac{dv}{d\tau}\right). \qquad (1)$$

2. *Examples.* *a.* Find the difference between the specific heat at constant volume and at constant pressure for perfect gases. We have

$$pv = R\tau;$$

$$\therefore \left(\frac{dp}{d\tau}\right) = \frac{R}{v} = \frac{p}{\tau},$$

$$\left(\frac{dv}{d\tau}\right) = \frac{R}{p},$$

which reduces equation (1) to

$$K_p - K_v = R = \frac{p_0 v_0}{\tau_0}, \qquad (2)$$

a well known result.

*b.* Find the difference of these specific heats for the imperfect gas represented by the equation

$$pv = R\tau - \frac{a}{\tau v},$$

We have

$$\left(\frac{dp}{d\tau}\right) = \frac{R}{v} + \frac{a}{\tau^2 v^2} = \frac{p}{\tau} + \frac{2a}{\tau^2 v^2},$$

$$\left(\frac{dv}{d\tau}\right) = \frac{R}{p} + \frac{a}{\tau^2 vp} = \frac{v}{\tau} + \frac{2a}{\tau^2 vp};$$

$$\therefore K_p - K_v = \frac{1}{\tau}\left(p + \frac{2a}{\tau v^2}\right)\left(v + \frac{2a}{vp}\right); \qquad (3)$$

which reduces to (2) for $a = 0$.

3. *Formula modified for liquids and solids.*

In equation (1) the value of $\frac{dv}{d\tau}$ may be found by direct experiment, but in the case of liquids and solids $\frac{dp}{d\tau}$, the rate of increase of pressure per unit of temperature cannot be readily found; and, generally, for such bodies in the atmosphere, the pressure may be constant while subjected to changes in temperature. The relation between volume and pressure may generally be approximated to by means of the coefficient of elasticity.

We have generally

$$p = f(v, \tau);$$

$$\therefore dp = \left(\frac{dp}{dv}\right) dv + \left(\frac{dp}{d\tau}\right) d\tau.$$

But if $p$ be constant, $dp = 0$, and we have for such a case:

$$0 = \left(\frac{dp}{dv}\right) dv + \left(\frac{dp}{d\tau}\right) d\tau;$$

$$\therefore \left(\frac{dp}{d\tau}\right) = -\left(\frac{dp}{dv}\right)\frac{dv}{d\tau},$$

which, substituted in (1), gives:

$$K_p - K_v = -\tau \left(\frac{dv}{d\tau}\right)^2 \left(\frac{dp}{dv}\right), \qquad (4)$$

which applies equally well to gases. The reciprocal of $\left(\frac{dp}{dv}\right)$ will be found by experiment.

4. *Examples.*

*a.* Applying this to the case of water, we first observe that at its maximum density under the constant pressure of the atmosphere, $\frac{dv}{d\tau} = 0$; for which condition equation (4) gives:

$$K_p = K_v,$$

or, the two specifics of water are equal at its maximum density.

*b.* Next, find the difference between these specific heats for water at 25° C. = 77° F. = 538.2° F. absolute.

The volume of a pound of water at its maximum density under the pressure of one atmosphere is 0.016 of a cubic foot, and as the coefficient of cubical expansion at 25° C. is 0.00025 per degree Centigrade, or 0.00014 nearly per degree F. at 77° F., we have:

$$\left(\frac{dv}{d\tau}\right)_p^2 = (0.016 \times 0.00014)^2 = 5 \times 10^{-12}.$$

We will take 0.01605 as the volume of one pound of water at 77° F. under the pressure of one atmosphere. The coefficient of compression for one atmosphere is 0.000046; hence the compression for one pound on a square foot will be:

$$\frac{dv}{dp} = \frac{0.01605 \times 0.000046}{2116.3} = 10^{-12} \times 350;$$

$$\therefore \frac{dp}{dv}=\frac{10^{12}}{350},$$

and equation (4) gives

$$K_p-K_v=538.2\times 3\tfrac{5}{9}=7.689,$$

which in ordinary heat units, becomes, by dividing by 772,

$$k_p-k_v=0.0099 \text{ very nearly.}$$

5. *Ratio of the specific heats.*

If at $b$ a tangent be drawn to the isothermal $bc$, and another to the adiabatic $bm_2$, and the isothermal $\tau+\triangle\tau$ approach $\tau$ indefinitely, we will ultimately have:

$$\frac{\tan.\ abc}{\tan.\ abd}=\frac{\frac{ac}{ab}}{\frac{ad}{ab}}=\frac{ac}{ad}$$

and the areas $m_1abm_2$ and $m_1acm_3$ will ultimately be as $ad$ to $ac$;

$$\therefore \frac{\tan.\ abc}{\tan.\ abd}=\frac{ac}{ad}=\frac{m_1acm_3}{m_1abm_2}=\frac{K_p d\tau}{K_v d\tau}=\frac{K_p}{K_v}. \quad (5)$$

The angle $abc$ is between the tangent to the isothermal and the ordinate $p$, and $abd$ is between the tangent to the adiabatic and the same ordinate. The value of this ratio deduced from equation (4) shows that it is dependent upon $K_v$, but that the ratio of the tangents is constant for perfect gases.

6. *A third equation of thermodynamics in which v and p are the independent variables.*

Let AcB (Fig. 2) be the ultimate path of the fluid; from A let the path, at first, be subjected to the condition that

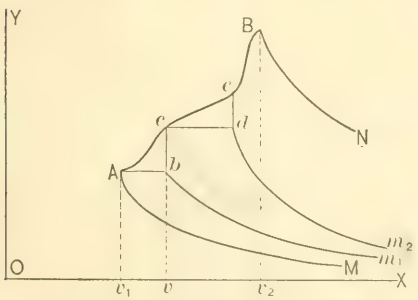


Fig. 2

the pressure is constant, then will the path be parallel to OX, which we call horizontal. If $K_p$ be the specific heat at constant pressure, the increase of temperature from A to $b$ being $d\tau$, while the length of A$b$ is $dv$, so that $\tau$ is a function of $v$, we then write

$$d_v\tau=\left(\frac{d\tau}{dv}\right)dv,$$

then will the heat represented by MA$bm_1$ be $K_p d_v\tau$.

At $b$ let the path be vertical to some point $c$ on the ultimate continuous path, for which $v$ will be constant, and if $K_v$ be the specific heat at constant volume, the heat $m_1bcm_2$ will be $K_v d_p\tau$ (the line $cm_2$ is not shown in the figure, and may be supplied by the reader); hence, ultimately, the heat

$$\text{MA}bcm_2=\text{MA}cm_2=dH=K_p d_v\tau+K_v d_p\tau$$
$$=K_p\left(\frac{d\tau}{dv}\right)dv+K_v\left(\frac{d\tau}{dp}\right)dp,$$

which is the differential equation sought. It may be reduced to another form by finding $\left(\frac{d\tau}{dv}\right)$ from (1), then $\left(\frac{d\tau}{dp}\right)$ from the same, substituting and reducing, giving

$$dH=\frac{\tau}{K_p-K_v}\left\{K_p\left(\frac{dp}{d\tau}\right)dv+K_v\left(\frac{dv}{d\tau}\right)dp\right\} \quad (6)$$

This form may be deduced directly from the two more common forms, which are:

$$dH=K_v d\tau+\tau\left(\frac{dp}{d\tau}\right)dv, \quad (7)$$

$$dH=K_p d\tau-\tau\left(\frac{dv}{d\tau}\right)dp; \quad (8)$$

by multiplying the former by $K_p$ and the latter by $K_v$ and subtracting; giving at once,

$$dH=\frac{\tau}{K_p-K_v}\left\{K_p\left(\frac{dp}{d\tau}\right)dv+K_v\left(\frac{dv}{d\tau}\right)dp\right\}.$$

If the path of the fluid be an isothermal, it would, at first sight, seem that equation (6) requires a knowledge of the specific heats in order to find the heat absorbed, whereas, according to equations (7) and (8) the specific heats disappear for $\tau$ constant. But for $\tau$ constant equations (7) and (8) give

$$\tau\left(\frac{dp}{d\tau}\right)dv=-\tau\left(\frac{dv}{d\tau}\right)dp,$$

and this, substituted in equation (6), gives

$$dH = \frac{\tau}{K_p - K_v}\left\{(-K_p + K_v)\left(\frac{dv}{d\tau}\right)dp\right\}$$

$$= -\tau\left(\frac{dv}{d\tau}\right)dp = \tau\left(\frac{dp}{d\tau}\right)dv,$$

which is the same as (6) and (7) for $\tau$ constant, showing that the apparent retention of the specific heats for this particular case is only apparent.

7. *Other processes.*

In this and the preceding article, the passage from A to B has been by three different combinations of paths: first, by isothermal and vertical lines; second, by horizontal and isothermal lines; and, third, by horizontal and vertical lines. It is evident that other elementary paths might be followed, as for instance, an isothermal followed by an adiabatic, and other combinations with the adiabatic, or the right lined paths might be oblique, but to make these combinations useful their properties must be known, which would add greatly to the complexity of the analysis without being of any advantage.

8. *The Second Law.*

We return again to the consideration of this much-discussed subject. The literature upon this subject shows that writers not only differ in the formal statement of the second law of thermodynamics, but, unfortunately, are not agreed as to what constitutes this law. Some even ignore it, and attempt to develop the subject from the first law only (like Zeuner), while others state the principles involved in the subject without dignifying them as *laws*. Thus, Rankine states two laws, and Sir William Thomson gives two propositions, the second of which depends for its demonstration upon the axiom, *It is impossible by means of inanimate material agency to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of surrounding objects.* (Math. and Phys. Papers, pp. 178, 179); and Clausius states a First Main Principle, a Second Main Principle, and a New Fundamental Principle, the last of which is contained in the axiom: "A passage of heat from a colder to a hotter body cannot take place without compensation."* (Clausius "Mechanical Theory of Heat," Browne's Translation, p. 78.) The question arises, What shall the second law be? Shall the two axioms just quoted be considered as the second law? They are not unfrequently referred to as such. McCulloch in his Mechanical Theory of Heat, page 162, states that Clausius' axiom was less obvious than Thomson's, but the latter writer claims that "either is a consequence of the other." (Papers, p. 181.) Or, shall we consider Rankine's second law as the only true second law? and if so, which of his several statements of it shall we accept as the valid one? for they are not identical, nor do they all cover the same ground. Or, shall we consider Thomson's and Clausius' extension of Carnot's principle of a reversible cycle as the second law?

One or another of these three general forms is referred to as the second law, but it would be more agreeable to the student if the second law were so defined as to be generally accepted and recognized as such. No philosopher has power to compel the acceptance of a principle, much less to restrict it a definite order. The statements of the founders of a science have great force with their followers, but where several investigators are engaged in the establishment of a science, as in this case, who do not agree in the formal statements of the principles upon which the science is founded, it belongs to others to restate or rearrange those principles. The fundamental principles of a science should be so simple that their truth cannot be seriously questioned, and so clearly stated that their meaning will be easily apprehended. Newton's three laws of motion are typical in this regard. The principles involved in them were all recognized by scholars before his day, but his predecessors had not so successfully formulated them. Writers develop the science of Mechanics without special reference to these laws, but they have, since Newton's day, generally been recognized as con-

* This axiom is stated in different ways. It was first formulated in 1854, *Pogg. Ann.*, xciii., and as published in the *Phil. Mag.*, 1856, (2), p. 86 reads: *Heat can never pass from a colder to a warmer body without some other change, connected therewith, occurring at the same time.* As given by Thomson in his Math. and Phys. Papers, page 181, it reads: *It is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature.*

taining the essential principles of the science, and, in teaching the subject, I have been in the habit of drilling the student thoroughly upon them. So, if this science is to be developed from formal laws, the latter should be few in number and as nearly fundamental as possible; and if the necessary principles cannot be contained in two laws let more be given.

The first law—the equivalence of heat and work—is conceded. The next step is to find the amount of heat absorbed when work is being done. The external work can be measured and some law must be established that will enable us to determine the internal work, for the total heat absorbed will equal the sum of the two works. In this general statement is included the heat which changes the temperature. The first step is to consider the case of expansion at constant temperature, for then the energy of the substance remains constant, and the entire heat absorbed from an external source is transmuted into work, external and internal. But heat cannot be absorbed from an external source, if the temperature of the source be less than that of the working substance. The axiom of Thomson or Clausius (speaking of the two axioms as one) lies at the very foundation of this operation—at the very foundation of doing work by expansion—and for this reason may be called the *second law* in the proper order and as a fundamental principle. Although qualitative, it none the less expresses a uniform mode of action. It is often referred to as the second law, although neither Thomson or Clausius set claim to it as such, so far as I have been able to determine. Thomson considers it as an axiom by means of which he is to prove his Proposition II. Clausius states it as a New Fundamental Principle by means of which he is to establish his Second Main Principle. Rankine recognizes it as a principle, but not as a formal law (*Steam Engine*, p. 224); also in the *Phil. Mag.*, 1865, and *Papers*, page 449, he says: "In an air-engine, under all circumstances whatsoever, *the heat produced by the compression of the air is wholly and unavoidably lost*—a principle which is a necessary consequence of the fact that heat never passes directly from a colder to a hotter body." The principle is re iterated on page 453 of *Papers*.

Maxwell says: "The law from which Carnot's principle is deduced has been called the Second Law of Thermodynamics;" and then quotes the axioms of Clausius and Thomson, but does not appear to be satisfied with the formal wording, for he suggests that an acquisition of the fact will be of more importance than any form of words (Maxwell on *Heat*, p. 153). While, therefore, this axiom, or these axioms, will remain as a recognized part of the science—*a fact*, as Rankine states it, yet, as a general rule, those who state a second law include in it a principle of measure—a quantitative element. Thus, Baynes in his book on Thermodynamics, pp. 69–73, after giving Clausius the credit of considering his New Principle as the Second Law, finally gives as *the* Second Law Thomson's generalization of Carnot's principle. Assuming that the above axiom, or axioms, are not to be considered as the second law, we have sought a wording which might be substituted for the numerous other ones, and which, instead of antagonizing, would harmonize with them, and have thus arrived at the following:

Second Law of Thermodynamics.—*When the temperature of a substance is maintained constant while doing work by expansion as the effect of heat only, the total work, both external and internal, equals the heat absorbed by the substance while doing such work.*

Or, a little more briefly, *when a substance does work by expanding at a constant temperature, the work done equals the heat absorbed.*

The analyst finds the algebraic expression for the heat absorbed at constant temperature to be $\tau\frac{dp}{d\tau}dv$ for the expansion $dv$, then, in accordance with the second law, writes:

$$dW = \tau\frac{dp}{d\tau}dv;$$

$$\therefore W = \tau\int\frac{dp}{d\tau}dv;$$

where W is the total work done.

The above proposed law is certainly correct if

$$Q = w K \tau,$$

in which K is the real dynamic specific heat of substance, $\tau$ the absolute temperature, $w$ the weight of the substance, and Q the quantity of actual heat in it. In regard to this relation, Rankine said, at the close of his celebrated paper on the Geometrical Representation of the Expansive Action of Heat: "Although existing experimental data may not be adequate to verify this principle precisely, they are still sufficient to prove that it is near enough to the truth for all purposes, connected with thermodynamic engines, and to afford belief that it is an exact physical law." (*Papers*, p. 409; Phil. Trans., 1854.) If the sensible heat of the substance remains constant during expansion, then its direct office will be to transform the heat energy absorbed at that temperature directly to the work done. Or, to put it in the form of a figure, the substance will be an agent whose office it is to transmit the heat energy committed to it and deliver its equivalent in the form of potential energy to another agent.

We now proceed to compare this statement with those of other writers.

Rankine's most general law of the transformation of energy is:

"*The effect of the whole actual energy present in a substance, in causing transformation of energy, is the sum of the effects of all its parts.*"

The symbolic expression of this law is:

$$Q \cdot \frac{dP}{dQ} \cdot dV \quad (9)$$

in which Q is the total actual energy possessed by the substance tending to increase the volume, V the volume of a pound of the substance, and P the resistance operating against the increase of V, and equals the intensity of the state V to increase. (Proceedings of the Phil. Soc. of Glasgow, Vol. III., No. 5; *Phil. Mag.*, 1853; *Papers*, pp. 204, 348, 375; Prime Movers, p. 309.)

The same law restricted to heat is stated as follows:

"*If the total actual heat of a homogeneous and uniformly hot substance be conceived to be divided into any number of equal parts, the effect of those parts in causing work to be performed are equal.*

The symbolic expression of the second law is:

$$Q \cdot \frac{d(du)}{dQ} \cdot \quad (10)$$

(Prime Movers, p. 306.) The same general law restricted to temperature is stated as follows:

"*If the absolute temperature of any uniformly hot substance be divided into any number of equal parts, the effects of those parts in causing work to be performed are equal.*"

This law is expressed algebraically as follows:

$$\tau \frac{d(du)}{d\tau} = Q \frac{d(du)}{dQ} \quad (11)$$

(Steam Engine, p. 307). The three forms just given are essentially the same, and their symbolic expressions (9), (10), (11), are equivalent; for, as has already been shown, (10) and (11) are equivalent to

$$\tau \frac{dp}{d\tau} dv = Q \frac{dp}{dQ} dv.$$

The algebraic expressions are understood to be the equivalent of the formal statements of the law, and hence may be used to interpret those statements. These expressions all involve the definite idea of isothermal expansion. Unfortunately for the student this idea is completely obscured in the establishment of the expression $Q \frac{d(du)}{dQ}$ by Rankine in his "Steam Engine," p. 306. The author says, "Let unity of weight of a homogeneous substance, possessing the actual heat Q, undergo any indefinitely small change, so as to perform the indefinitely small amount of work $d$U." In order that work be performed there must be a change of volume, but the law of that change is not implied. Indeed, the language, "any indefinitely small change," leaves the student unfamiliar with the subject, free to infer that the change may be arbitrary and therefore not necessarily restricted to an isothermal expansion. But the above expression is true only for such expansion, and the author has so expressed himself in the graphical solution in his "Steam Engine," page 308, and in the third paragraph on p. 310, and also in his Scientfic Papers, page 311. This idea being vital

in the analysis, we are led to consider, in the first and second statements above given, that the substance is merely an agent for transmitting the heat energy absorbed to another agent of the potential form, which form may be visible energy (work), or partly visible and partly internal. internal excluding change of temperature.

Since the office of this agent is to cause "transformation of energy," the substance should (and in this case must) have its energy conserved, which involves the idea of a constant temperature. If its own energy were increased by the absorption of heat, it would not "transmit" all the energy imparted to it, and if its temperature was diminished it would be performing another office than that of "transmitter.:' The assertion that "the effect is the sum of the effects of all its parts" is an assertion not proved, but one which appeals to our judgment for assent—and one to which assent will generally be given.

In the second statement we detect the idea of a uniform temperature in doing work in the expression "*in causing work to be performed*," for the parts may be conceived of as not doing the work, but simply as the agents for transmitting the heat absorbed, which heat does the work; and since the energy of the agents—the parts—is unimpaired, the total work done will equal the heat absorbed. The reason given by the author for the equal parts performing equal effects is "all the equal parts are equally circumstanced;" but it may appear more plausible if we consider the physical conditions, thus—if the substance be homogeneous and uniformly hot, and absorbs heat during expansion, the velocity with which heat travels is so great it will reach all parts of a finite mass in sensibly the same time, thus preserving a sensibly uniform temperature in all parts. The real proof of the proposition, however, consists in "the agreement of its results with those of experiment" (Papers. p. 437), and it has thus been confirmed in many ways. The "work performed" necessarily includes all the work done, and so includes internal as well as external.

Granting that our interpretations of these two laws are correct, we see no good reason for their being stated in such an abstract manner as virtually to hide their meaning, or, at least, compelling the student to become familiar with the subject before understanding the fundamental law. We now proceed to other statements. In a paper read before the British Association in 1865, Rankine wrote as follows:

"SECOND LAW.—*The quantity of energy which is converted from one of these forms to the other during a given change of dimensions and condition in a given body, is the product of the absolute temperature into a function of that change, and of the kind and condition of the matter of the body.*" (*Phil. Mag.*, Oct., 1865; Papers, p. 427.) A somewhat more complete form of this statement is in his *Steam Engine*, p. 309.

Here, as before, the law of change is not assigned, but we recognize in it a rather loose but general statement of the algebraic formula $\tau \int \frac{dp}{d\tau} dv$, which, as before stated, is established on the condition of isothermal expansion, and is a measure of the heat absorbed at constant temperature. It is the value involved in our proposed second law.

Two years later we find another statement which is still more explicit. In an article in *The Engineer* for June, 1867, we find the following:

"The second law shows to what extent the mutual conversion of heat and work takes place under given circumstances, (Papers, p. 432.)

"The second law is capable of being stated in a variety of forms; the most convenient for the present purpose appears to be the following:

"*To find the whole work, internal and external, multiply the absolute temperature at which the change of dimensions takes place, by the rate per degree at which the external work is varied by a small variation of temperature.*" (Papers, p. 434.)

Here we have, for the first time, the explicit statement that the symbolic expression of the second law gives "the whole work, internal and external." Isothermal expansion is implied in the expression "temperature at which the change of dimensions takes place," and "the rate per degree at which the external work is varied by a small variation of the temperature" is expressed algebraically thus:

$$\frac{d\mathrm{U}}{d\tau}=\frac{dpdv}{d\tau}=\frac{dp}{d\tau}dv,$$

so that if $d\mathrm{W}$ be an element of the whole work the above law will be expressed symbolically thus:

$$d\mathrm{W}=\tau\frac{d\mathrm{U}}{d\tau}=\tau\frac{dp}{d\tau}dv,$$

which is precisely what results from our proposed formal statement.

In the article just referred to is another statement of the law, which we do not italicize because it is evidently incomplete, its chief object being apparently to emphasize one element of the preceding statement. It is:

"The law affects the solution by deducing the total work, internal and external, from the manner in which a small variation of temperature affects the external work." (Papers, p. 436.) Multiplying by the absolute temperature and expanding at constant temperature are omitted in this statement.

In the same article is another statement, as follows:

"If the substance which does work in a perfect heat engine receives all the heat expended at one fixed temperature, and gives out all the heat which remains unconverted into work at a lower fixed temperature, the fraction of the whole heat expended which is converted into external work, is expressed by dividing the difference between these temperatures by the higher of them, reckoned from the absolute zero. Now this is, in fact, the second law of thermodynamics expressed in other words." (Papers, p. 437).

This we regard as a somewhat loose and unguarded statement of the second law, for it does not agree with any of the author's other statements of it. This is a mere ratio, while the second law is a measure of a quantity—being the heat transferred during a definite operation. If it be assumed that the entire heat absorbed is unity, then will the value of this ratio be numerically the same as the quantity utilized, but even then the *idea* of the two expressions are by no means coincident, for one remains a ratio —a mere number—while the other is a quantity. It, however, involves the essence of the second law in the fact that it measures the transfer of heat to work under the conditions that all the heat is supplied at one fixed temperature, and all that is abstracted is at another fixed lower temperature. There is also the incidental difference that the last statement involves a cycle, while the other statements involve expansion only—or the reverse, but this is not vital, since one assumption may be made the consequence of the other. To show this, we first correct the last definition by inserting after the word "zero," the expression, "and the entire heat transferred into work will be the product of this ratio into all the heat received at the higher temperature." Now the heat received at the fixed temperature $\tau$ is known to be $\tau\int\frac{dp}{d\tau}dv$; hence between the temperatures $\tau$ and $\tau_2$, the heat transmuted into work will be, by the law,

$$\frac{\tau-\tau_2}{\tau}\cdot\tau\int\frac{dp}{d\tau}dv.$$

Let $\tau_2$ approach $\tau$ indefinitely, then ultimately

$$\tau-\tau_2=d\tau,$$

and the preceding expression becomes

$$d\tau\int\frac{dp}{d\tau}dv,$$

which is a fundamental expression for the heat absorbed for an elementary change $d\tau$. Or, from the expression $\tau\frac{dp}{d\tau}dv$ we readily deduce the value for the total heat transferred, as is well known. The last quotation commits Rankine to the same idea of the essence of the second as that of Maxwell, Clausius and Thomson, which is—such an expression as will be a foundation for producing Carnot's cycle.

We now consider Clausius' second main principle. On page 90 of the "Mechanical Theory of Heat," of the edition of 1875, translated by Browne, 1879, is the following:

"The second Main Principle of the Mechanical Theory of Heat, so far as it relates to reversible processes, may be expressed as follows: *If in a reversible Cyclical Process every element of heat taken in (positive or negative) be divided by the absolute temperature at which it is taken in, and the differential so formed be integrated for the whole course of the process, the integral so obtained is zero.*

It follows from this that $\frac{dQ}{\tau}$ must be the perfect differential of a quantity, which depends only on the present condition of the body, and is altogether independent of the way in which it has been brought into that condition. If we denote this quantity by S, we may put

$$\frac{dQ}{\tau} = dS$$

or

$$dQ = \tau dS.''$$

The cyclical process described is known as Carnot's Cycle. The value of $dS$, given later in the work, corresponds with Rankine's thermodynamic function; but the first development of it is for a fixed temperature, and this part of the process corresponds with our formal statement of the second law.

On pages 91 and 92 is another statement, as follows:

"Two transformations are produced, a transformation from heat into work, and a transformation from heat of a higher temperature to heat of a lower. The relation between these two transformations is therefore that which is to be expressed by the second Main Principle." This involves only the principle deducible from our proposed second law. Again on page 100:

"Hence the second Main Principle of the Mechanical Theory of Heat, which in this form may perhaps be called the Equivalence of Transformations, &c." This, as we have already seen, is the central idea of the second law, but the context shows that the author used it in a broader sense than proposed in our statement of the second law, inasmuch as he includes in it all the heat absorbed by the substance during the change and may thus involve a change of temperature. But we repeat the fact that the algebraic expression for this result is reached by first considering an isothermal change in which the amount of expansion may be indefinitely small, followed by an indefinitely small increase of temperature, as was shown in the preceding number of this Magazine. There is then no difficulty in dividing the most general idea, or statement of the Second Main Principle, into two parts; one the transfer of heat at constant temperature, the other the change of energy of the substance due to absorbing more heat than is necessary to maintain the uniform temperature. Indeed, the author has treated it in this manner, deducing the expressions $\tau\frac{dp}{d\tau}dv$ and $-\tau\frac{dv}{d\tau}dp$, considering these as partial differentials of Q, then on page 178 finding the partial differentials of Q dependent upon a change of temperature only, the respective sums of which give the total differentials of Q; or

$$dQ = C_v d\tau + \tau\frac{dp}{d\tau}dv.$$

Turning now to Thomson's statement, we have, on page 178 of his Mathematical and Physical Papers, the following:

"Prop. II (Carnot and Clausius). If an engine be such that, when it is worked backwards, the physical and mechanical agencies in every part of its motions are reversed, it produces as much mechanical effect as can be produced by any thermodynamic engine, with the same temperatures of source and refrigerator, from a given quantity of heat."

On page 179 is another statement in more familiar language, as follows: "Now let there be no molecular change or alteration of temperature in any part of the body or, by a cycle of operations, let the temperature and physical condition be restored exactly to what they were at the beginning; the work done by its own molecular forces, and the amount by which the half *vis viva* of the thermal motions of all its parts is diminished vanish; and we conclude that the heat which it emits or absorbs will be the thermal equivalent of the work done upon it by external forces, or done by it against external forces; which is the proposition to be proved."

Thomson finds for the heat absorbed during an expansion $dv$ at a constant temperature, the algebraic expression

$$M dv = \tau\frac{dp}{d\tau}dv.$$

in which the factor $\tau$ was determined by experiment. This proposition II. is deducible from our proposed second law, and, as we have seen, the symbolic expression of the second law is deducible from this Prop. II.

It is unnecessary to consider the state-

ments of other writers on this point. Any proposed second law that does violence to the principles set forth by the founders of the science will not be received; and others must judge whether our proposed formal statement of this law is proper and acceptable. We note that the substance, and indeed almost our literal statement may be extracted from the above second quotation of Thomson's, thus: "Now let there be no alteration of temperature in any part of the body; the amount by which the half *vis viva* of the thermal motions of all its parts is diminished vanish; and we conclude that the heat which it emits or absorbs will be the thermal equivalent of the work done upon it, or done by it; which is the proposition to be proved." We do not claim that Thomson intended to put the statement in a form such that it would be valid when thus dissected, or that he even recognized the fact that it could be so separated, but our present knowledge of the subject renders it perfectly legitimate to do so. It divides his statement into two propositions, one applicable to expansion or compression, the other to an operation making a reversible cycle.

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## ANALYSIS OF ROTARY MOTION, AS APPLIED TO THE GYROSCOPE.

By MAJOR J. G. BARNARD, A.M.

After reading most of the popular explanations of the above phenomenon given in our scientific and other publications, I have found none altogether satisfactory. While, with more or less success, they expose the more obvious features of the phenomenon and find in the force of gravity an efficient cause of horizontal motion, they usually end in destroying the foundation on which their theory is built, and leave an effect to exist *without a cause;* a horizontal motion of the revolving disk about the point of support is supposed to be accounted for, while the descending motion, which is the first and direct effect of gravity (and without which no horizontal motion can take place), is ignored or supposed to be entirely eliminated. Indeed, it is gravely stated as a distinguishing peculiarity of rotary motion, that, while gravity acting upon a non-rotating body causes it to descend vertically, the same force acting upon a rotary body causes it to *move horizontally. A tendency to descend* is supposed to produce the effect of an *actual descent;* as if, in mechanics, a mere tendency to motion ever produced any effect whatever without that motion actually taking place.

Whatever "mystification" there may be in analysis—however it may hide its results under symbols unintelligible save to the initiated, it is most certain that the greater portion of the physical phenomena of the universe are utterly beyond the grasp of the human mind without its aid. The mind can—indeed it *must*—search out the inducing causes, bring them together and adjust them to each other, each in its proper relation to the rest; but farther than that (at least in complicated phenomena) unaided, it cannot go. It cannot *follow* these causes in all their various actions and reactions and at a given instant of time bring forth the results.

This, analysis alone can do. *After* it has accomplished this, it indeed usually furnishes a clue by which to trace how the workings of known mechanical laws have conspired to produce these results. This clue I now propose to find in the analysis of rotary motion as applied to the gyroscope.

The analysis I shall present, so far as determining the equations of motions is concerned, is mainly derived from the works of Poisson (vide "Journal de l'Ecole Polytech." vol. XVI—Traité de Mécanique, vol II, p. 162). Following his steps and arriving at his analytical results, I propose to develop fully their meaning, and to show that they are expressions not merely of a visible phenomenon, but that they contain within them-

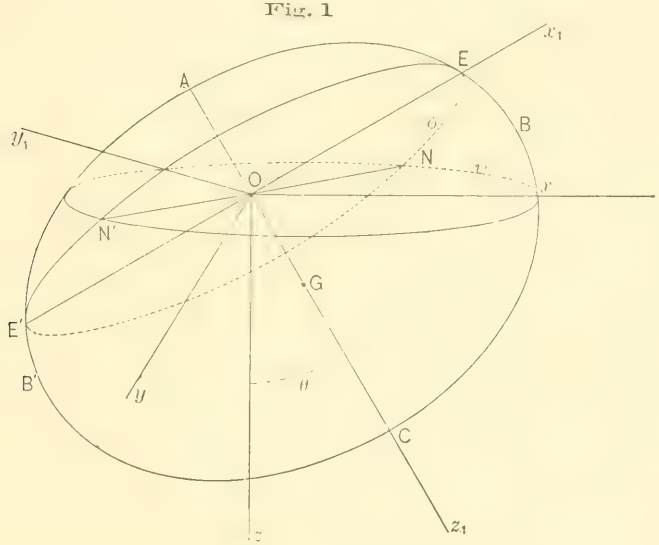
selves the sole clue to its explanation; while they dispel all that is mysterious or paradoxical, and in reducing it to merely a "particular case" of the laws of "rotary motion," throw much light upon the significance and working of those laws.

Although not unfamiliar to mathematicians, it may not be uninteresting to those who have not time to go through the long preliminary study necessary to enable them to take up with Poisson this special investigation, or whose studies in mechanics have led them no farther than to the general equations of "rotary motion," found in text books, to show how the particular equations of the gyroscopic motion may be deduced.

In the above expressions the rotating body (of any shape) ABCD, Fig. 1, is supposed retained by the *fixed* point within or without its mass) O. $Ox$, $Oy$ and $Oz$ are the three co-ordinate axes, *fixed in space*, to which the motion of the body is referred. $Ox_1$, $Oy_1$, $Oz_1$, are the three *principal axes* belonging to the point O, and which, of course, partake of the body's motion. The position of the body at any instant of time is determined by those of the moving axes.

A, B and C express the several "moments of inertia" of the mass with reference, respectively, to the three principal axes $Ox_1$ $Oy_1$ $Oz_1$; $N_1$, $M_1$ and $L_1$ are the moments of the *accelerating forces*,

Fig. 1




In so doing I shall closely follow him; making, however, some few modifications for the sake of brevity and of avoiding the use of numerous auxiliary quantities not necessary to the limited scope of this investigation.

The general equations of rotary motion are (see Prof. Bartlett's "Analytical Mechanics," Equations (228), p. 170):

$$\left.\begin{aligned} C\frac{dv_z}{dt} + v_x v_y (B - A) &= L_1 \\ B\frac{dv_y}{dt} + v_x v_z (A - C) &= M_1 \\ A\frac{dv_x}{dt} + v_y v_z (C - B) &= N_1 \end{aligned}\right\} \quad (1)$$

and $v_x$, $v_y$, $v_z$, the *components of rotary velocity*, all taken with reference to these same axes.

Like lineal velocities, velocities of rotation may be decomposed—that is, a rotation about any single axis may be considered as the resultant of components about other axes (which may always be reduced to three rectangular ones): and by this means, about whatever axis the body, at the instant we consider, may be revolving, its actual velocity and axis are determined by a knowledge of its components $v_x$, $v_y$, $v_z$ about the principal axes $Ox_1 Oy_1 Oz_1$, these components being, as with lineal velocities, equal to the resultant velocity multiplied by the cosine

of the angles their several rectangular axes make with the resultant axis.

As the true axis and rotary velocity may continually vary, so the components $v_x, v_y, v_z$, in equations (1) are variable functions of the time.

For the purpose of determining the axes $Ox_1$, $Oy_1$ and $Oz_1$, with reference to the (fixed in space) axes $Ox$, $Oy$, $Oz$, three auxiliary angles are used

If we suppose the moving plane of $x_1 y_1$, at the instant considered, to intersect the fixed plane of $xy$ in the line NN′ and call the angle $xON = \psi$, and the angle between the planes $xy$ and $x_1y_1$ (or the angle $zOz_1) = \theta$, and the angle $NOx_1 = \varphi$, (in the figure, these three angles are supposed *acute* at the instant taken) these three angles will determine the positions of the axes $Ox_1$, $Oy_1$, $Oz_1$, (and hence of the body) at any instant, and will themselves be functions of the time; and the rotary velocities $v_x$, $v_y$, $v_z$, may be expressed in terms of them and of their differential coefficients.

For this purpose, and for use hereafter in our analysis, it is necessary to know the values, in terms of $\varphi$, $\theta$ and $\psi$, of the cosines of the angles made by the axes $Ox_1$, $Oy_1$ and $Oz_1$ with the fixed axes $Oz$ and $Oy$.

These values are shown to be (vide Bartlett's Mech., p. 172)

$$\cos.\ x_1Oz = -\sin.\ \theta \sin.\ \varphi$$
$$\cos.\ y_1Oz = -\sin.\ \theta \cos.\ \varphi$$
$$\cos.\ z_1Oz = \cos.\ \theta$$
$$\cos.\ x_1Oy = \cos.\ \theta \cos.\ \psi \sin.\ \varphi - \sin\ \psi \cos.\ \varphi$$
$$\cos.\ y_1Oy = \cos.\ \theta \cos.\ \psi \cos\ \varphi + \sin.\ \psi \sin\ \varphi$$
$$\cos.\ z_1Oy = \sin.\ \theta \cos.\ \psi$$

The differential angular motions, in the time $dt$, about the axes $Ox_1$, $Oy_1$, $Oz_1$, will be $v_x dt$, $v_y dt$, and $v_z dt$. We may determine the values of these motions by applying the laws of composition of rotary motion to the rotations indicated by the increments of the angles $\theta$, $\varphi$ and $\psi$.

If $\theta$ and $\varphi$ remain constant, the increment $d\psi$ would indicate that amount of angular motion about the axis $Oz$ perpendicular to the plane in which this angle is measured. In the same manner $d\varphi$ would indicate angular motion about the axis $Oz_1$; while $d\theta$ indicates rotation about the line of nodes ON. In using these three angles, therefore, we actually refer the rotation to the three axes $Oz$, $Oz_1$, ON, of which one, $Oz$, is fixed in space, another, $Oz_1$, is fixed in and moves with the body, and the third, ON, is shifting in respect to both.

The angular motion produced around the axes $Ox_1$, $Oy_1$, $Oz_1$, by these simultaneous increments of the angles $\varphi$, $\theta$ and $\psi$, will be equal to the sum of the products of these increments by the cosines of the angles of these axes, respectively, with the lines $Oz$, $Oz_1$ and ON.

The axis of $Oz_1$ for example makes the angles $\theta$, 0° and 90° with these lines, hence the angular motion $v_z dt$ is equal (taking the sum without regard to sign) to $\cos.\ \theta d\psi + d\varphi$.

In the same manner (adding without regard to signs),

$$v_x dt = \cos.\ x_1Oz d\psi + \cos.\ \varphi d\theta$$

and $v_y dt = \cos.\ y_1Oz d\psi + \cos.\ (90° + \varphi) d\theta$.

But if we consider the motion about $Oz_1$ indicated by $d\varphi$, positive, it is plain from the directions in which $\varphi$ and $\psi$ are laid off on the figure, that the motion $\cos.\ \theta d\psi$ will be in the reverse direction and negative, and since $\cos.\theta$ is positive $d\psi$ must be regarded as negative, hence

$$v_z dt = d\varphi - \cos.\ \theta d\psi$$

The first term of the value of $v_x dt$, $\cos.\ x_1Oz d\psi$ [since $\cos.\ x_1Oz\ (= -\sin.\theta \sin.\ \varphi)$ is negative and $d\psi$ is to be taken with the negative sign] is positive. But a study of the figure will show that the rotation referred to the axis $Ox_1$, indicated by the first term of this value, is the reverse of that measured by a positive increment of $\theta$ in the second, and hence, (as $\cos.\ \varphi$ is positive,) $d\theta$ must be considered negative. Making this change and substituting the values given of $\cos.\ x_1Oz$, $\cos.\ y_1 Oz$, and for $\cos.\ (90° + \varphi)$, $-\sin.\ \varphi$, we have the three equations

$$\left.\begin{aligned} v_x dt &= \sin.\ \theta \sin.\ \varphi d\psi - \cos.\ \varphi d\theta \\ v_y dt &= \sin.\ \theta \cos.\ \varphi d\psi + \sin.\ \varphi d\theta \\ v_z dt &= d\varphi - \cos.\ \theta d\psi \end{aligned}\right\} \quad (2)^*$$

The general equations (1) are susceptible of integration only in a few particular cases. Among these cases is that we con-

* To avoid the introduction of numerous quantities foreign to our particular investigation and a tedious analysis, I have departed from Poisson and substituted the above simple method of getting equations (2.), which is an instructive illustration of the principles of the composition of rotary motions.

sider, viz., that of a *solid of revolution* retained by a fixed point *in its axis of figure*.

Let the solid ABCD, Fig. 1, be supposed such a solid, of which $Oz_1$ is the axis of figure. It will be, of course, a principal axis, and any two rectangular axes in the plane, through O perpendicular to it, will likewise be principal. By way of determining them, let $Ox_1$ be supposed to pierce the surface in some arbitrarily assumed E point in this plane. Let G be the center of gravity (gravity being the sole accelerating force). The moments of inertia A and B become equal, and equations (1) reduce to

$$\left.\begin{aligned} &Cdv_z=0\\ &Adv_y-(C-A)v_zv_xdt=\gamma a\mathrm{M}gdt\\ &Adv_x+(C-A)v_yv_zdt=-\gamma b\mathrm{M}gdt \end{aligned}\right\} \quad (3)^*$$

in which the distance OG of the point of support from the center of gravity is represented by $\gamma$, $g$ is the force of gravity, M the mass and $a$ and $b$ stand for the cosines $x_1Oz$ and $y_1Oz$ and of which the values are (p. 52)

$$a=-\sin.\ \theta\ \sin.\ \varphi, \qquad b=-\sin.\ \theta\ \cos.\ \varphi.$$

The first equation (3) gives by integration $v_z=n$, $n$ being an arbitrary constant; it indicates that the rotation about the axis of figure remains always constant.

Multiplying the two last equations (3) by $v_y$ and $v_x$ respectively and adding the products, we get

$$\mathrm{A}(v_ydv_y+v_xdv_x)=\gamma\mathrm{M}g(av_y-bv_x)dt.$$

From the values of $a$ and $b$ above, and from those $v_x$ and $v_y$ (equations 2) it is easy to find

$$(av_y-bv_x)dt=-\sin.\ \theta\ d\theta=d.\cos.\ \theta;$$

substituting this value and integrating and calling $h$ the arbitrary constant

$$\mathrm{A}(v_y^2+v_x^2)=2\gamma\mathrm{M}g\ \cos.\ \theta+h. \qquad (a)$$

Multiplying the two last equations (3), respectively, by $b$ and $a$ and adding and reducing by the value just found of $d.\cos.\ \theta$ and of $v_z$, we get

$$\mathrm{A}(bdv_y+adv_x)+(\mathrm{C}-\mathrm{A})nd.\ \cos.\ \theta=0 \quad (b)$$

Differentiating the values of $a$ and $b$ and referring to equations (2) it may readily be verified (putting for $v_z$ its value $n$) that

$$db=(v_x\ \cos.\ \theta-an)dt$$
$$da=(bn-v_y\ \cos.\ \theta)dt$$

and multiplying the first by $\mathrm{A}v_y$ and the second by $\mathrm{A}v_x$, and adding

$$\mathrm{A}(v_ydb+v_x\,da)=\mathrm{A}n(bv_x-av_y)dt$$
$$=-\mathrm{A}nd.\ \cos.\ \theta.$$

Adding this to equation $(b)$, we get

$\mathrm{A}d.(bv_y+av_x)+\mathrm{C}nd.\ \cos.\ \theta=0$, the integral of which is

$$\mathrm{A}(bv_y+av_x)+\mathrm{C}n\ \cos.\ \theta=l\ (l \text{ being an arbitrary constant}). \qquad (c)$$

Referring to equations (2) it will be found by performing the operations indicated, that:

$$v_x^2+v_y^2=\sin.^2\theta\frac{d\psi^2}{dt^2}+\frac{d\theta^2}{dt^2}$$

$$bv_y+av_x=-\sin.^2\theta\frac{d\psi}{dt}$$

Substituting these values in equations $(a)$ and $(c)$, we get

$$\mathrm{C}n.\ \cos.\theta-\mathrm{A}\ \sin.^2\theta\frac{d\psi}{dt}=l$$

$$\mathrm{A}\left(\sin.^2\theta\frac{d\psi^2}{dt^2}+\frac{d\theta^2}{dt^2}\right)=2\mathrm{M}g\gamma\ \cos.\ \theta+h$$

If, at the origin of motion, the axis of figure is simply deviated from a vertical position by an arbitrary angle $\alpha$, in the plane of $xz$, and an arbitrary velocity $n$ is imparted about this axis alone; then $v_x$ and $v_y$ will at that instant be zero, $\theta=\alpha$, and the substitution of these values in equations $(a)$ and $(c)$ will determine the values of the constants $l$ and $h$.

$$h=-2\mathrm{M}g\gamma\ \cos.\ \alpha$$
$$l=\mathrm{C}n\ \cos.\ \alpha,$$

which, substituted in the above equations, make them

$$\left.\begin{aligned} &\sin.^2\theta\frac{d\psi}{dt}=\frac{\mathrm{C}n}{\mathrm{A}}(\cos.\ \theta-\cos.\ \alpha)\\ &\sin.^2\theta\frac{d\psi^2}{dt^2}+\frac{d\theta^2}{dt^2}=\frac{2\mathrm{M}g\gamma}{\mathrm{A}}\\ &\qquad\qquad(\cos.\ \theta-\cos.\ \alpha) \end{aligned}\right\} \quad (4)$$

These together with the last equation (2) which may be written, (substituting the value of $v_z$)

$$d\varphi=ndt+\cos.\ \theta d\psi \qquad (5)$$

* See Bartlett's Mech. Equations (225) and (118) for the values of $L_1$ $M_1N_1$; in the case we consider the extraneous force P (of eq. 118) is $g$; the co-ordinates $x'$, $y'$ of its point of application G (referred to the axes $Ox_1$, $Oy_1$, $Oz_1$,) are zero and $z^1=OG=\gamma$; cosines of $\alpha$, $\beta$ and $\gamma$ are $a$, $b$ and $c$; hence $L_1=0$, $M_1\gamma aMg$, $N_1=-\gamma bMg$.

will (if integrated) determine the three angles $\varphi$, $\theta$ and $\psi$ in terms of the time $t$. They are therefore the differential equations of motion of the gyroscope.

Let NEE′, (Fig. 1,) be a section of the solid by the plane $x_1$ $y_1$. This section may be called the *equator*. E being some fixed point in the equator (through which the principal axis $Ox_1$ passes), the angle $\varphi$ is the angle EON.

If N is the *ascending node* of the equator—that is, the point at which E in its axial rotation *rises above* the horizontal plane, the angle $\varphi$ must increase from N towards E—that is, $d\varphi$ (in equation 5) must be positive and (as the second term of its value is usually very small compared to the first) the angular velocity $n$ must be positive. That being the case the value of $d\varphi$ will be exactly that due to the constant axial rotation $ndt$, augmented by the term cos. $\theta d\psi$, which is the projection on the plane of the equator of the angular motion $d\psi$ of the node. This term is an increment to $ndt$ when it is positive, and the reverse when it is negative. In the first case, the motion of the node is considered *retrograde*—in the second, *direct*.

The first member of the second equation (4) being essentially positive, the difference cos. $\theta$—cos. $\alpha$ must be always positive—that is, the axis of figure $Oz$, can never rise *above* its initial angle of elevation $\alpha$. As a consequence $\frac{d\psi}{dt}$ [in first equation (4)] must be always positive. The node N, therefore, moves always in the direction in which $\psi$ is laid off positively, and the motion will be direct or retrograde, with reference to the axial rotation, according as cos. $\theta$ is negative or positive—that is, as the axis of figure is above or below the horizontal plane. In either case the motion of the node in its own horizontal plane is always progressive in the same direction. If the rotation $n$ were reversed, so would also be the motion of the node.

If this rotation $n$ is zero, $\frac{d\psi}{dt}$ must also be zero and the second equation (4) reduces at once to the equation of the compound pendulum, as it should. Eliminating $\frac{d\psi}{dt}$ between the two equations (4) we get

$$\sin.^2\theta\frac{d\theta^2}{dt^2}=\frac{2Mg\gamma}{A}\left[\sin.^2\theta-\frac{C^2n^2}{2AM\gamma g}(\cos.\theta-\cos.\alpha)\right](\cos.\theta-\cos.\alpha).$$

The length of the simple pendulum which would make its oscillations in the same time as the body (if the rotary velocity $n$ were zero) is $\frac{A}{M\gamma}$.* If we call this $\lambda$ and make for simplicity $\frac{C^2n^2}{2A^2g}=\frac{2\beta^2}{\lambda}$ the above equation becomes

$$\sin.^2\theta\frac{d\theta^2}{dt^2}=\frac{2g}{\lambda}[\sin.^2\theta-2\beta^2(\cos.\theta-\cos.\alpha)](\cos.\theta-\cos.\alpha) \quad (6)$$

and the first equation (4) becomes

$$\sin.^2\theta\frac{d\psi}{dt}=2\beta\sqrt{\frac{g}{\lambda}}(\cos.\theta-\cos.\alpha \quad (7)$$

Equation (6) would, if integrated, give the value of $\theta$ in terms of the time; that is, the inclination which the axis of figure makes at any moment with the vertical; while eq. (7) (after substituting the ascertained value of $\theta$) would give the value of $\psi$ and hence determines the progressive movement of the body about the vertical $Oz$.

These equations in the above general form, have not been integrated;† nevertheless they furnish the means of obtaining all that we desire with regard to gyroscopic motion, and in particular that self-sustaining power, which it is the particular object of our analysis to explain.

In the first place, from eq. (6), by putting $\frac{d\theta}{dt}$ equal to zero, we can obtain the maximum and minimum values of $\theta$. This diff. coefficient is zero, when the factor cos. $\theta$—cos. $\alpha$=0, that is, when $\theta=\alpha$; and this is a *maximum*, for it has just been shown from equations (4) that $\theta$ cannot exceed $\alpha$. It will be zero also and $\theta$ a *minimum*‡ when

$$\sin.^2\theta-2\beta^2(\cos.\theta-\cos.\alpha)=0$$

or $$\cos.\theta=-\beta^2+\sqrt{1+2\beta^2\cos.\alpha+\beta^4} \quad (8)$$

* The length of the simple pendulum is (see Bartlett's Mech., p. 252) $\lambda=\frac{k_1^2+\gamma^2}{\gamma}$. The moment of inertia $A=M(k_1^2+\gamma^2)$; hence $\frac{A}{M\gamma}=\lambda$.

† The integration may be effected by the use of elliptic functions; but the process is of no interest in this discussion.

‡ It is easy to show that this value of $\theta$ belongs to an actual minimum; but it is scarcely worth while to introduce the proof.

(The positive sign of the radical alone applies to the case, since the negative one would make $\theta$ a greater angle than $\alpha$)

It is clear that ($\alpha$ being given) the value of $\theta$ depends on $\beta$ alone, and that it can never become zero unless $\beta$ is zero; and as long as the impressed rotary velocity $n$ is not itself zero (however minute it may be), $\beta$ will have a finite value.

Thus, however minute may be the velocity of rotation, it is sufficient to prevent the axis of rotation *from falling to a vertical position.*

The self-sustaining power of the gyroscope when very great velocities are given *is but an extreme case of this law.* For, if $\beta$ is very great, the small quantity $1-\cos.^2\alpha$ may be subtracted from the quantity under the radical (eq. 8) without sensibly altering its value, which would cause that equation to become

$$\cos.\theta=\cos.\alpha$$

That is, when the impressed velocity $n$, and in consequence $\beta$ is very great, the minimum value of $\theta$ differs from its maximum $\alpha$ by an exceedingly minute quantity.

Here then is the result, analytically found, which so surprises the observer, and for which an explanation has been so much sought and so variously given. The revolving body, though solicited by gravity, *does not visibly fall.*

Knowing this fact, we may *assume* that the impressed velocity $n$ is very great, and hence $\cos.\theta-\cos.\alpha$ exceedingly minute, and on this supposition, obtain integrals of equations (6) and (7), which will express with all requisite accuracy the true gyroscopic motion. For this purpose, make

$$\theta=\alpha-u, \qquad d\theta=-du$$

in which the new variable $u$ is always extremely minute, and is the angular descent of the axis of figure below its initial elevation.

By developing and neglecting the powers of $u$ superior to the square, we have

$$\sin.^2\theta=\sin.^2\alpha-u\sin.2\alpha+u^2\cos.2\alpha^*$$

$$\cos.\theta-\cos.\alpha=u\sin.\alpha-\tfrac{1}{2}u^2\cos.\alpha$$

substituting these values in eq. 6, we get

$$\sqrt{\frac{g}{\lambda}}dt=\frac{du}{\sqrt{2u\sin.\alpha-u^2(\cos.\alpha+4\beta^2)}}.\dagger$$

$\beta$ having been assumed very great, $\cos.\alpha$ may be neglected in comparison with $4\beta^2$ and the above may be written

$$\sqrt{\frac{g}{\lambda}}dt=\frac{du}{\sqrt{2u\sin.\alpha-4\beta^2u^2}}. \qquad (d)$$

Integrating and observing that $u=o$, when $t=o$, we have

$$\sqrt{\frac{g}{\lambda}}.t=\frac{1}{2\beta}.\text{arc}\left\{\cos.=1-\frac{4\beta^2u}{\sin.\alpha}\right\}$$

(*See Appendix, Note A.*)

$$u=\frac{\sin.\alpha}{4\beta^2}\left(1-\cos.2\beta\sqrt{\frac{g}{\lambda}}.t\right)$$

or, (since $\cos.2\alpha=1-2\sin.^2\alpha$)

$$u=\frac{1}{2\beta^2}\sin.\alpha\sin.^2\beta\sqrt{\frac{g}{\lambda}}.t \qquad (9)$$

Putting $\alpha-u$ in place of $\theta$ (equat. 7) neglecting square of $u$, we get

$$\frac{d\psi}{dt}=\frac{1}{\beta}\sqrt{\frac{g}{\lambda}}.\sin.^2\beta\sqrt{\frac{g}{\lambda}}.t \qquad (10)$$

(*See Appendix, Note B.*)

from which, observing that $\psi=0$, when $t=0$

$$\psi=\frac{1}{2\beta}\sqrt{\frac{g}{\lambda}}.t-\frac{1}{4\beta^2}\sin.\left(2\beta\sqrt{\frac{g}{\lambda}}.t\right) \qquad (11)$$

These three expressions (9), (10), (11), represent the vertical angular depression —the horizontal angular velocity—and the extent of horizontal angular motion of the axis of figure after any time $t$.‡

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* By Stirling's theorem,

$$f(u)=\text{U}+\text{U}'\frac{u}{1}+\text{U}''\frac{u^2}{1.2},\ \&c.,$$

in which U, U', U'' &c. are the values of $f(u)$ and its different coefficients when $u$ is is made zero.

Making $f(u)=\sin.^2(\alpha-u)$, and recollecting that $\sin.2u=2\sin.u\cos.u$ and $\cos.2u=\cos.^2u-\sin^2u$, we get the value of $\sin.^2\theta$; and making $f(u)=\cos.(\alpha-u)-\cos.\alpha$ the value in text of $\cos.\theta-\cos.\alpha$ is obtained.

† Eq. 6 may be written

$$\frac{\lambda}{g}\frac{d\theta^4}{dt^2}=2(\cos.\theta-\cos.\alpha)-4\beta^2\frac{(\cos.\theta-\cos.\alpha)^2}{\sin.^2\theta}.$$

By substituting the values just found of $d\theta$, $\sin.^2\theta$ and $\cos.\theta-\cos.\alpha$ and performing the operations indicated, neglecting the higher powers of $u$, (by which $\frac{(\cos.\theta-\cos.\alpha)^2}{\sin.^2\theta}$ reduces simply to $u^2$) and deducing the value $\sqrt{\frac{g}{\lambda}}dt$, the expression in the text is obtained.

‡ The assumption that $\psi=0$ when $t$ is zero supposes that the initial position of the node coincides with the fixed axis of $x$. In my subsequent illustrations and analysis I suppose the initial position to be at 90° therefrom, which would require to the above value of $\psi$, the constant $\frac{1}{2}\pi$ to be added. The horizontal angular motion of the axis of figure is the same as that of the node.

The first two will reach their respective maxima and minima when sin. $\beta\sqrt{\frac{g}{\lambda}}\,t = 1$ and $=0$; or when $t=\frac{\pi}{2\beta}\sqrt{\frac{\lambda}{g}}$ and $t=\frac{\pi}{\beta}\sqrt{\frac{\lambda}{g}}$.

These values of $t$ in equation (11) give

$$\psi=\frac{\pi}{4\beta^2} \qquad \psi=\frac{\pi}{2\beta^2}$$

Hence, counting from the commencement of motion, when $t$, $u$, $\frac{d\psi}{dt}$ and $\psi$ are all zero, we have the following series of corresponding values of these variables

$$t=\frac{\pi}{2\beta}\sqrt{\frac{\lambda}{g}},\quad u=\frac{1}{2\beta^2}\text{sin. } a \quad \frac{d\psi}{dt}=\frac{1}{\beta}\sqrt{\frac{g}{\lambda}} \quad \psi=\frac{\pi}{4\beta^2}$$

which correspond to the moment of greatest depression, when $u$ and $\frac{d\psi}{dt}$ are maxima and

$$t=\frac{\pi}{\beta}\sqrt{\frac{\lambda}{g}},\quad u=0, \frac{d\psi}{dt}=0,\ \psi=\frac{\pi}{2\beta^2},$$

when, it appears ($u$ being the zero), the axis of figure has regained its original elevation and the horizontal velocity is destroyed.

All these values are (owing to the assumed large value of $\beta$) very minute. If we suppose the rotating velocity $n=100\,\pi$ or 100 revolutions per second, the maximum of $u$ (with an instrument of ordinary proportions) would be a fraction of a minute of arc, and the period of undulation but a fraction of a second.

Hence the horizontal motion about the point of support will be exceedingly slow compared with the axial rotation of the disk expressed by $n$.

If, in equations (9) and (10), we increase $t$ indefinitely we will have but a repetition of the series of values already found, they being recurring functions of the time.

We see, then, the revolving body *does not*, in fact, maintain a uniform unchanging elevation, and move about its point of support at a uniform rate, (as it appears to do). But the axis of figure generates what may be called a *corrugated cone*, and any point of it would describe an undulating curve (Fig. 2) whose superior culminations $a$, $a'$, $a''$, &c., are *cusps* lying in the same horizontal plane, and whose sagittae $cb$, $c'b'$, &c., are to the amplitudes $aa'$, $a'a''$ &c., as $\frac{\text{sin. } a}{2\beta^2} : \frac{\pi}{2\beta^2} :: \text{sin. } a : \pi$. If the initial elevation $a$ is 90°, this ratio is *as the diameter to the circumference of the circle:* a property which indicates the *cycloid.*

Assuming $a=90°$ and sin. $a=1$, equations (9) and (10) will give, by elimination of $\text{sin.}^2\beta\sqrt{\frac{g}{\lambda}}\,t$,

Fig. 2




$$\frac{d\psi}{dt}=2\beta\sqrt{\frac{g}{\lambda}}u \qquad dt=\frac{d\psi}{2\beta\sqrt{\frac{g}{\lambda}}u},$$

substituting this value in eq. ($d$), we get

$$d\psi=\frac{2\beta\,u\,d\,u}{\sqrt{2u-4\beta^2u^2}}=\frac{u\,d\,u}{\sqrt{\frac{1}{2\beta^2}u-u^2}}$$

*the differential equation of the cycloid* generated by the circle whose diameter is $\frac{1}{2\beta^2}$

In this position of the axis, both the angles $u$ and $\psi$ are arcs of great circles described by a point of the axis of figure at a units distance from O, and owing to their minuteness may be considered as rectilinear co-ordinates.

If $a$ is not 90°, the sagittae $bc=\frac{1}{2\beta^2}$ sin. $a$; but then, while the angular motion $\psi$ is the same, the arc described by the same point of the axis will be that of a *small circle*, whose actual length will

likewise be reduced in the ratio of 1 : sin.$a$. The curve is therefore a cycloid in all circumstances; and the axis of figure moves as if it were attached to the circumference of a minute circle whose diameter is $\frac{1}{2\beta^2}\sin.\ a$, which rolled along the horizontal circle, $a\ a'\ a''$, about the vertical through the point of support.

The center $e$ of this little circle moves with uniform velocity. The *first term* of the value of $\psi$ (equation 11) is due to this uniform motion; it may be called the *mean precession.*

The second term is due to the circular motion of the axis about this center, and combined with the corresponding values of $u$, constitutes what may be called the *nutation.*

These cycloidal undulations are so minute—succeed each other with such rapidity (with the high degreees of velocity usually given to the gyroscope), that they are entirely lost to the eye, and the axis seems to maintain an unvarying elevation and move around the vertical with a uniform slow motion.

It is in omitting to take into account these minute undulations that nearly all popular explanations fail. They fail, in the first place, because they substitute, in the place of the real phenomenon, one which is purely imaginary and *inexplicable*, since it is in direct variance with fact and the laws of nature;—and they fail, because these undulations—(great or small, according as the impressed rotation is small or great) furnish the only true clue to an understanding of the subject.

The fact is, that the phenomenon exhibited by the gyroscope which is so striking, and for which explanations are so much sought, is only a *particular and extreme phase* of the motion expressed by equations (6) and (7)—that the self-sustaining power is not absolute, but one of degree—that, however minute the axial rotation may be, the body never will fall quite to the vertical;—however great, it cannot sustain itself without any depression.

I have exhibited the undulations, as they exist with high velocities—when they become minute and nearly true cycloids; with low velocities they would occupy (horizontally) a larger portion of the arc of a semi-circle, and reach downward approximating, more or less nearly, to contact with the vertical; and, *finally*, when the rotary velocity is zero, their cusps are in diametrically opposite points of the horizontal circle, while the curves resolve themselves into vertical circular arcs which coincide with each other, and the vibration of the pendulum is exhibited. All these varieties of motion, of which that of the pendulum is one extreme phase and the gyroscopic another, are embraced in equations (6) and (7) and exhibited by varying $\beta$ from 0 to high values, though (wanting general integrals to these equations) we cannot determine, except in these extreme cases, the exact elements of the undulations. The minimum value of $\theta$ may, however, always be determined by equation (8).

If we scrutinize the *meaning* of equations (6) and (7), it will be found that they represent, the first, the horizontal angular component of the velocity of a point at units distance from O, and the second the actual velocity of such point.*

For $\sin.\theta\frac{d\psi}{dt}$ is the horizontal, and $\frac{d\theta}{dt}$ the vertical, component of this velocity. Calling the first $v_h$, and the second $v_v$, and the resultant $v_s$, and calling cos. $\theta$ − cos $a$ (which is the true height of fall), $h$, those equations may be written

$$v_h = \frac{Cn}{A}\ \frac{h}{\sin.\ \theta} \qquad (e)$$

$$({v_h}^2 + {v_v}^2) = {v_s}^2 = \frac{2g}{\lambda}h \qquad (f)$$

This velocity $v_s$ (as a function of the height of fall) is exactly that of *the compound pendulum*, and is *entirely independent of the axial rotation n.* Hence (as we might reasonably suppose) rotary motion has no power to impair the work of gravity *through a given height*, in gen-

*In more general terms equations(4) express the first, that the *moment of the quantity of motion* about the fixed vertical axis Oz remains always constant; the *second* that the living forces generated in the body (over and above the *impressed* axial rotation) are exactly what is *due to gravity through the height, h.*

Both are expressions of truths that might have been anticipated; for gravity cannot increase the moment of the quantity of motion about an *axis parallel to itself;* while its power of generating living force by working through a given height, cannot be impaired.

Had we consider d ourselves at liberty to assume them, however, the equations might have been got without the tedious analysis by which we have reached them.

erating velocity; but it does have power to *change the direction of that velocity.* Its effect is precisely that of a material undulatory curve, which, deflecting the body's path from vertical descent, finally directs it upward, and causes its velocity to be destroyed by the same forces which generated it.

And it may be remarked, that, were the cycloid we have described *such a material curve,* on which the axis of the gyroscope rested, without friction and *without rotation,* it would travel along this curve by the effect of gravity alone (the velocity of descent on the downward branch carrying it up the ascending one), with *exactly the same velocity* that the rotating disk does, through the combined effects of gravity *and* rotation.

Equation (*a*) expresses the horizontal velocity produced by the rotation.

If we substitute its value in the second we may deduce

$$v_v \text{ or } \frac{d\theta}{dt} = \sqrt{\frac{2g}{\lambda}}h - \frac{C^2n^2}{A^2}\,\frac{h^2}{\sin.^2\theta}$$

If we take this value at the commencement of descent, *and before any horizontal velocity is acquired* (making $h$ indefinitely small), the second term under the radical may be neglected, and the first increment of descending velocity be comes $\sqrt{\frac{2g}{\lambda}}h$, precisely what is due to gravity, and *what it would be were there no rotation.*

Hence the popular idea that a rotating body offers any *direct* resistance to a change of its plane, is unfounded. It requires as little exertion of force (in the direction of motion) to move it from one plane to another, as if no rotation existed; and(as a corollary) as little expenditure of work.

But deflecting forces are developed, by angular motion given to the axis, and normal to its direction, which are very sensible, and are mistaken for *direct* resistances. If the extremity of the axis of rotation were confined in a vertical circular groove, in which it could move without friction; or if any similar fixed resistance, as a matarial vertical plane, were opposed to the *deflecting* force, the rotating disk would vibrate in the vertical plane as if no rotation existed. Its equation of motion would become that of the compound pendulum, $\frac{d\theta}{dt} = \sqrt{\frac{2g}{\lambda}}h$. What then is the resistance to a change of plane of rotation so often alluded to and described. A *misnomer* entirely.

The above may be otherwise established. If in equations (3) we introduce in the second member an indeterminate horizontal force, $g'$, applied to the center of gravity, parallel to the fixed axis of $y$, and contrary to the direction in which, in our figure, we suppose the angle $\psi$ to increase, the projections of this force on the axes $Ox_1$, $Oy_1$, will be $a'\,g'$ and $b'\,g'$ and the last two of these equations will become (calling cosines $x_1\,Oy$ and $y_1Oy_1$ a' and $b'$,)

$$A\,dv_y - (C-A)nv_x\,dt = \gamma M(ag + a'g')dt$$
$$A\,dv_x + (C-A)nv_y dt = -\gamma M(bg + b'g')dt$$

Multiplying the first by $v_y$ and the second by $v_x$ and adding

$$A(v_y dv_y + v\ dv_x) = \gamma M[g(av_y - bv_x)dt + g'(a'v_y - b'v_x)dt]$$

But $(av_y - bv_x)dt$ has been shown (p. 53) to be $= d.\cos.\theta$,—and by a similar process it may be shown that $(a'v_y - b'v_x)dt = d.(\sin.\theta \cos.\psi)$. (For values of $a'$ and $b'$ see p. 52.)

Let us suppose now that the force $g'$ is such that the axis of the disk may be always maintained in the plane of its initial position $xz$. The angle $\psi$ would always be 90°, $d\psi = 0$, and $d.(\sin.\theta \cos.\psi) = 0$. That is, the co-efficient of the new force $g'$ becomes zero; and the integral of the above equation is as before (p. 54),

$$A(v_y^2 + v_x^2) = 2\gamma Mg \cos.\theta + h.$$

But the value of $v_y^2 + v_x^2$ likewise reduces (since $\frac{d\psi}{dt} = 0$) to $\frac{a\theta^2}{dt^2}$ and the above becomes the equation of the compound pendulum $(g)$ $\frac{d\theta^2}{dt^2} = \frac{2\gamma Mg}{A}\cos.\theta + h = \frac{2g}{\lambda}$ (cos. $\theta$—cos. $a$), ($h$ being determined.) This is the principle just before announced, that, with a force so applied as to prevent any *deflection* from the plane in which gravity tends to cause the axis to vibrate, the motion would be precisely *as if no axial rotation existed.*

To determine the force of $g'$; multiply the first of preceding equations by $b$, and the second by $a$, and add the two,

and add likewise $A(v_y db + v_x da = -A\ nd$ cos. $\theta$ (see p. 54), and we shall get

$$Ad(bv_y + av_x) + C\ nd \cos.\ \theta = \gamma M g' (a'b - ab')dt.$$

By referring to the values of $a, a', b, b'$, and performing the operations indicated and making cos. $\psi = o$, sin. $\psi = 1$, the above becomes,

$$Ad(bv_y + av_x) + C\ nd \cos.\ \theta = \gamma M g' \sin.\ \theta\ dt.$$

But the value of $(bv_y + av_x)$ (p. 54) becomes zero when $\frac{d\psi}{dt} = o$. Hence,

$$g' = \frac{C\ nd \cos.\ \theta}{\gamma M \sin.\ \theta\ dt} = -\frac{Cn\ d\theta}{\gamma M\ dt}*$$

The second factor $\frac{d\theta}{dt}$ is the *angular velocity* with which the axis of rotation is moving.

Hence calling $v_s$ that angular velocity, *the value of the deflecting force*, $g'$ may be written (irrespective of signs),

$$g' = \frac{C}{\gamma M} n v_s. \qquad (h)$$

that is, it is directly proportional *to the axial rotation* $n$, and *to the angular velocity* of the axis of that rotation. By putting for $C,Mk^2$ (in which $k$ is the distance from the axis at which the mass M, if concentrated, would have the moment of inertia, C,) the above takes the simple form

$$g' = \frac{k^2}{\gamma} n v_s.$$

In the case we have been considering above, in which $g'$ is supposed to counteract the deflecting force of axial rotation, the angular velocity $v_s$ or $-\frac{d\theta}{dt}$ (equation $g$) is equal to $\sqrt{\frac{2g}{\lambda}(\cos.\ \theta - \cos.\ a)}$

But in the case of the *free* motion of the gyroscope, this deflecting force combines with gravity to produce the observed movements of the axis of figure.

If, *therefore*, we *disregard* the axial rotation and consider the body simply as fixed at the point O, and acted upon, at the center of gravity, by two forces—one of gravity constant in intensity and direction—the other, the *deflecting* force due to an axial rotation $n$, whose variable intensity is represented by $\frac{C}{\gamma M} n v_s$, and whose direction is always normal to the plane of motion of the axis; we ought, introducing these forces, and making the axial rotation $n$ zero, in general equations (3), to be able to deduce therefrom the identical equations (4) which express the motion of the gyroscope.

This I have done; but as it is only a verification of what has previously been said, I omit in the text the introduction of the somewhat difficult analysis.

(*See Appendix, Note C.*)

Equation (5) becomes (in the case we consider), by integration;

$$\varphi = nt + \psi \cos.\ a$$

which, with the values of $u$ and $\psi$ already obtained, determines completely the position of the body at any instant of time.

Knowing now not only the exact nature of the motion of the gyroscope, but the direction and intensity of the forces which produce it, it is not difficult to understand why such a motion takes place.

Fig. 1 represents the body as supported by a point *within* its mass; but the analysis applies to any position, in the axis of figure, within or without; and Figs. 3 and 4 represent the more familiar circumstances under which the phenomenon is exhibited.

Let the revolving body be supposed (Fig. 3, vertical projection), for simplicity of projection, an exact *sphere*, supported by a point in the axis prolonged at O, which has an initial elevation $a$ greater than 90°. Fig. 4. represents the projection on the horizontal plane $xy$; the initial position of the axis of figure (being in the plane of $xz$) is projected in $Ox$.

$Ox$, $Oy$, $Oz$, are the three (fixed in space) co-ordinate axes, to which the body's position is referred.

In this position, an initial and high velocity $n$ is supposed to be given about the axis of figure $Oz_1$, so that the visible portions move in the direction of the arrows $b$, $b'$, and the body is left sub-

* The effect of gravity is to diminish $\theta$ and the increment $d\theta$ is negative in the case we are considering. Hence the negative sign to the value of $g'$, indicating that the force is in the direction of the *positive* axis of $y$, as it should, since the tendency of the node is to move in the reverse direction.

Fig. 3

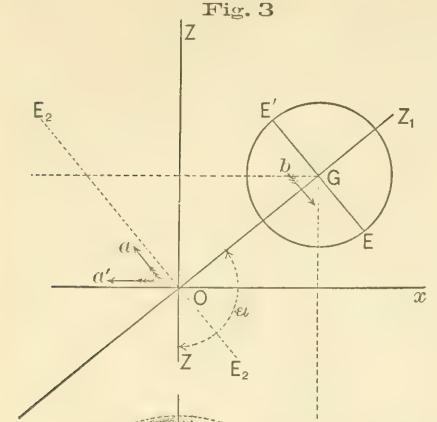
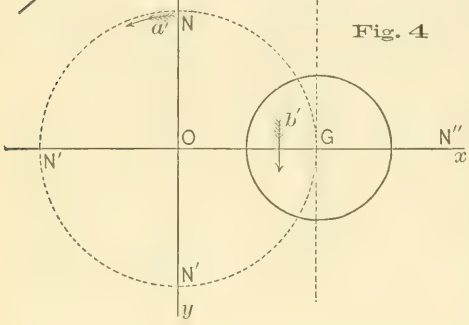



Fig. 4



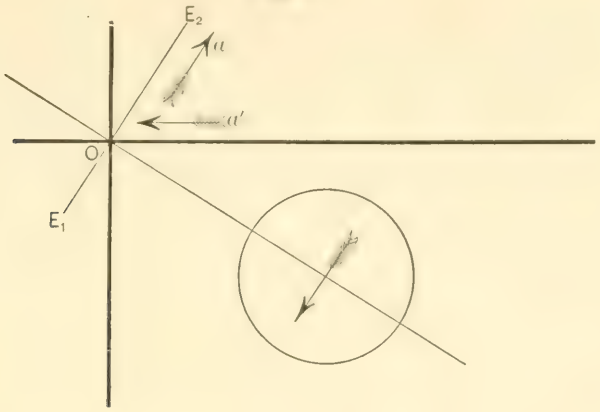

ject to whatever motion about its point of support O, gravity may impress upon it. Had it no axial rotation, it would immediately fall and vibrate according to the known laws of the pendulum. Instead of which, while the axis maintains (apparently) its elevation $a$, it moves slowly around the vertical Oz, receding from the observer, or from the position ON″ towards ON.

It is self-evident that the first *tendency* (and as I have likewise proved, the first effect) of gravity is to cause the axis $Oz_1$ to descend vertically, and to generate vertical *angular velocity*. But with this angular velocity, the *deflecting* force proportional to that velocity and normal to its direction, is generated, which pushes aside the descending axis from its vertical path. But as the direction of motion changes, so does the direction of this force—always preserving its perpendicularity. It finally acquires an intensity and upward direction adequate to neutralize the downward action of gravity; but the *acquired downward velocity* still exists and the axis *still* descends, at the same time acquiring a constantly increasing horizontal component, and with it a still increasing upward deflecting force. At length the descending component of velocity is entirely destroyed—the path of the axis is horizontal; the deflecting force due to it acts directly contrary to gravity, which it exceeds in intensity, and hence causes the axis to commence rising. This is the state of things at the point $b$ (Fig. 2). The axis has descended the curve $ab$, and has acquired a velocity due to its *actual* fall $ad$; but this velocity has been deflected to a *horizontal direction*. The *ascent* of the branch $ba'$ is precisely the converse of its descent. The *acquired* horizontal velocity impels the axis horizontally, while the deflecting force due to it (now at its maximum) causes it to commence ascending. As the curve bends upward, the normal direction of this force opposes itself more and more to the horizontal, while gravity is equally counteracting the vertical velocity. As the *horizontal* velocity at $b$ was due to a fall through the height $ad$, so, through the medium of this deflecting force, it is just capable of restoring the *work* gravity had expended and *lifting* the axis back to its original elevation at $a'$, and the cycloidal undulation is completed, to be again and again repeated, and the axis of figure, performing undulations too rapid and too minute to be perceived, moves slowly around its point of support.

Referring to Fig. 3, the *equator* of the revolving body (a plane perpendicu ar to the axis of figure and *through the fixed point* O,) would be an imaginary plane $E_1E_2$. Its intersection with the horizontal plane of $xy$ would be the line of nodes N,N′. In the position delineated, the progression of the nodes is *direct*. For, at the *ascending* node N, any point in the imaginary plane of the equator (supposed to revolve with the body) would move *upwards* in the direction of the arrow $a$, while the node moves in the *same direction from* O (of the arrow $a'$). Were the axis of figure below the horizontal plane, (Fig. 5) the upward rotation of the point would be from O to $E_2$ (as the arrow $a$), while the progression of the node (in the same direction as before as the arrow $a'$) would be the reverse, and the motion of the node would be *retrograde*—yet in both cases the same in space.

As the deflecting force of rotary mo-

Fig. 5

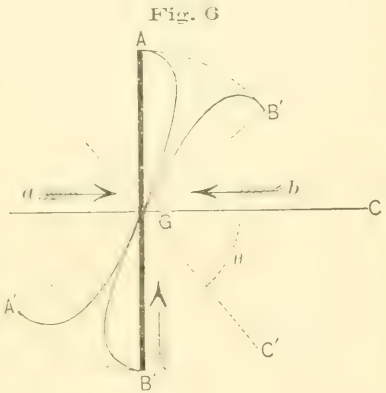



tion is the sole agent in diverting the vertical velocity produced by gravity from its downward direction, and in producing these paradoxical effects; and as the foregoing analysis, while it has determined its value, has thrown no light upon its origin, it may be well to inquire how this force is created.

Popular explanations have usually turned upon the deflection of the *vertical* components of rotary velocity by the vertical angular motion of the axis produced by gravity. In point of fact, however, *both* vertical and horizontal components are deflected, one as much as the other; and the simplest way of studying the effects produced, is to trace a vertical projection of the path of a point of the body under these combined motions. For this purpose conceive the mass of the revolving disk concentrated in a single ring of matter of a radius $k$ due to its moment of inertia $C=Mk^2$ (see Bartlett Mech. p. 178), and, for simplicity, suppose the angular motion of the axis to take place around the center figure and of gravity G.

Let AB be such a ring (supposed perpendicular to the plane of projection) revolving about its axis of figure GC, while the axis turns *in the vertical plane* about the same point G. Let the rotation be such that the visible portion of the disk moves upward through the semi-circumference, from B to A, while the axis moves downward through the angle $\theta$ to the position GC'. The point B, by its *axial rotation* alone, would be carried to A; but the plane of the disk, by simultaneous movement of the axis, is carried to the position A'B', and the point B arrives at B' instead of A, through the curve projected in BGB'. The equation of the projection, in circular functions, is easily made; but its general character is readily perceived, and it is sufficient to say that it passes through the point G,—that its tangents at B and B' are perpendicular to AB and A'B',—and that its concavity throughout its whole length turned to *the right*. The point A descends on the other, or remote side of the disk, and makes an exactly similar curve AGA' with its concavity reversed.

Fig. 6




The *centrifugal* forces due to the deflections of the vertical motions are normal to the concavities of these curves; hence, on the side of the axis *towards* the eye, they are to the *left*, and on the opposite or further side, to the *right*, (as the arrows $b$ and $a$.) Hence the joint effect is to

press the axis GC from its vertical plane CGC′, horizontally and towards the eye. Reverse the direction of axial rotation and the curves AA′ and BB′ will be the same except that AA′ would be on the *near* and BB′ on the *remote* side of the axis GC, and the direction of the resulting pressure will be reversed.

A projection on the horizontal plane would likewise illustrate this deflecting force and show at the same time that there is *no resistance in the plane of motion of the axis*, and that the whole effect of these deflections of the paths of the different material points, is a mere *interchange of living forces between the different material points of the disk;* but it is believed that the foregoing illustration is sufficient to explain the *origin* of this force, whose measure and direction I have analytically demonstrated.

It may be remarked, however, that the intensity of the force will evidently be directly as the velocities *gained and lost* in the motion of the particles from one side of the axis to the other; or as the *angular velocity of the axis*, and as the distance, $k$, of the particles from that axis. It will also be as the *number of particles* which undergo this gain and loss of living force in a given time; or *as the velocity of axial rotation.* Considered as applied normally at G to produce rotation about *any* fixed point O in the axis, its intensity will evidently be *directly* as the arm of lever $k$, and *inversely* as the distance of G from O ($\gamma$). Hence the measure of this force already found, from analysis,

$$g' = \frac{k^2}{\gamma} n v_s.$$

In the foregoing analysis, the entire ponderable mass is supposed to partake of the impressed rotation about the axis of figure $Oz_1$; and such must be the case im order that the results we have arrived at may rigidly apply. Such, however, cannot be the case in practice. A portion of the instrument must consist of mountings which do not share in the rotation of the disk. It is believed the analysis will apply to this case by simply including the *whole mass*, in computing the moment of inertia A and the mass M, while the moment C represents, as before, that of *the disk alone.*

In this manner it would be easy to calculate what *amount of extraneous* weight (with an *assumed* maximum depression $u$) the instrument would sustain, with a given velocity of rotation.

The analogy between the minute motions of the gyroscope and that grand phenomenon exhibited in the heavens,—the "precession of the equinoxes"—is often remarked. In an ultimate analysis, the phenomena, doubtless, are identical; yet the immediate causes of the latter are so much more complex, that it is difficult to institute any profitable comparison.

At first sight the undulatory motion attending the precession, known as "nutation" (nodding) would seem identical with the undulations of the gyroscope. But the identity is not easily indicated; for the earth's motion of nutation is mainly governed by the moon, with whose cycles it coincides; and the solar and lunar precessions and nutations are so combined, and affected by causes which do not enter into our problem, that it is vain to attempt any minute identification of the phenomena, without reference to the difficult analysis of celestial mechanics.

On a preceding page I said that a horizontal motion of the rotating disk around its point of support, without descending undulations, was at variance with the laws of nature. This assertion applied, however, only to the actual problem in hand, in which no other external force than gravity was considered, and no other initial velocity than that of axial rotation.

Analysis shows, however, that an initial *impulse* may be applied to the rotating disk in such a way that the horizontal motion shall be absolutely without undulation. An initial horizontal angular velocity, such as would make its corresponding deflective force equal to the component of gravity, $g \sin. \theta$, would cause a horizontal motion *without* undulation.

If the axial rotation $n$, as well as the horizontal rotation, is communicated by an impulsive force, analysis shows that it may be applied in *any plane* intersecting the horizontal plane *in the line of nodes;* but if applied in the plane of the equator (where it can communicate nothing but an *axial* rotation $n$), or in the horizontal plane, its intensity must be infinite.

My announced object does not carry

me further into the consideration of the gyroscope than the solution of this peculiar phenomenon, which depends solely upon, and is so illustrative of, the laws of rotary motion.

If I have been at all successful in making this so often explained subject more intelligible—in giving clearer views of some of the supposed effects of rotation, it has been because I have trusted solely to the *only* safe guide in the complicated phenomena of nature, *analysis*.

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APPENDIX.—NOTE A.

$\frac{du}{\sqrt{2u \sin. a - 4\beta^2 u^2}}$ may be put in the form $\frac{2\beta}{\sin. a} \cdot \frac{\frac{\sin. a}{4\beta^2} du}{\sqrt{2u \frac{\sin. a}{4\beta^2} - u^2}}$

Call $\frac{\sin. a}{4\beta^2} = R$, and the integral of the 2d factor of the above is the arc whose radius is R and versed sine is $u$; or whse cosine is $R-u$, or it is R *times* the arc whose cosine $1-\frac{u}{R}$ with radius unity. Substituting the value of R in the integral and multiplying by the factor $\frac{2\beta}{\sin. a}$ we get the value of $\sqrt{\frac{g}{\lambda}}t$, of the text.

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NOTE B.

In eq. (7) if we divide both members by $\sin.^2 \theta$, and, in reducing the fraction $\frac{\cos. \theta - \cos. a}{\sin.^2 \theta.}$, use the values already found and neglect the *square*, as well as higher powers $u$, (which may be done without sensible error, owing to the minuteness of $u$, though it could not be done in the foregoing values of $dt$ and $t$, since the co-efficient $4\beta^2$ in those values, is reciprocally great, as $u$ is small) the quotient will be simply $\frac{u}{\sin. a}$

Substituting the value of $u$ and dividing out sin. $a$, we get the value of $\frac{d\psi}{dt}$ in the text.

The integral of $\sin.^2 \beta \sqrt{\frac{g}{\lambda}} t dt$ results from the formula $\int \sin.^2 \varphi d\varphi = \frac{1}{2}\varphi - \frac{1}{4} \sin. 2\varphi$, easily obtained by substituting for $\sin.^2 \varphi$, its value $\frac{1}{2} - \frac{1}{2} \cos. 2\varphi$.

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NOTE C.

To introduce these forces in Eq. (3) I observe, first, that as both are applied at G (in the axis $Oz_1$) the moment $L_1$ is still zero and the *first* eq. becomes, as before

$$C dv_z = 0 \text{ or } v_z = \text{const.}$$

And as we disregard the impressed axial rotation, we make this constant (or $v_z$) zero.

The deflecting force $\frac{Cn}{\gamma M} v_s$ (taken with contrary sign to the *counteracting* force just obtained) resolves itself into two components $\frac{Cn}{\gamma M} \frac{d\theta}{dt}$ and $-\frac{Cn}{\gamma M} \frac{d\psi}{dt} \sin. \theta$, the first in a horizontal, the second in a vertical plane, and both normal to the axis of figure.

The second is opposed to gravity, whose component normal to the axis of figure is $g \sin. \theta$.

Hence we have the two component forces (in the directions above indicated),

$$M. \frac{Cn}{\gamma M} \frac{d\theta}{dt} \text{ and } M\left(g - \frac{Cn}{\gamma M} \frac{d\psi}{dt}\right) \sin. \theta.$$

These moments with reference to the axes of $y_1$ and $x_1$ will be

$$-\sin. \varphi \gamma M \left(g - \frac{Cn}{\gamma M} \frac{d\psi}{dt}\right) \sin. \theta - \cos. \varphi \gamma M \frac{Cn}{\gamma M} \frac{d\theta}{dt}, \text{ and}$$

$$\cos. \varphi \gamma M \left(g - \frac{Cn}{\gamma M} \frac{d\psi}{dt}\right) \sin. \theta - \sin. \varphi \gamma M \frac{Cn}{\gamma M} \frac{d\theta}{dt}$$

Hence equations (3) (making $v_z$ zero, and putting for $M_1$ and $N_1$ the above values, and recollecting the values of $a$ and $b$, (p. 53) become.

$$\left.\begin{aligned} A dv_y &= a_\gamma M g dt - \\ &\quad a C n \frac{d\psi}{dt} dt - C n \cos.\ \varphi \frac{d\theta}{dt} dt \\ A dv_x &= -b_\gamma M g dt + \\ &\quad b C n \frac{d\psi}{dt} dt - C n \sin.\ \varphi \frac{d\theta}{dt} dt \end{aligned}\right\} i$$

Multiplying the equations severally by $v_y$ and $v_x$, adding and reducing (as on p. 53) we get

$$A(v_y\, dv_y + v_x\, dv_x) = \gamma M g d. \cos.\theta - C n \frac{d\psi}{dt} d. \cos.\theta - C n d\theta\, (v_y \cos.\psi + v_x \sin.\varphi)$$

But $v_y \cos.\varphi + v_x \sin.\varphi$ will be found equal to $\sin.\theta \frac{d\psi}{dt}$ (by substituting the values of $v_y$ and $v_x$); hence the two last terms destroy each other, and the above equation becomes identical with equation ($a$) from which the 2d eq. (4) is deduced.

Multiplying the 1st equation ($i$) by cos. $\varphi$ and the second by sin. $\varphi$ and adding, we get

$$A(\cos.\ \varphi dv_y + \sin.\ \varphi dv_x) = -C n d\ \theta.$$

By differentiating the values of $v_y$ and $v_x$, performing the multiplications, and substituting for $d\varphi$ its value, cos. $\theta d\psi$, (proceeding from the 3d equation (2) when $v_z = 0$), the above becomes

$$A\left(\sin.\ \theta \frac{d^2\psi}{dt^2} + 2 \cos.\ \theta \frac{d\psi}{dt} \frac{d\theta}{dt}\right) = -C n \frac{d\theta}{dt}.$$

Multiplying both members by sin. $\theta dt$, and integrating, the above becomes

$$\sin.^2\ \theta \frac{d\psi}{dt} = \frac{C n}{A} \cos.\ \theta + l;$$

the same as the 1st equation (4) when the value of the constant $l$ is determined.

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## COMPARATIVE ECONOMY.

By ARTHUR COBB, C. E.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

The simple laws which govern the growth of interest upon money are very easily reduced, by algebraic analysis, to convenient formulæ which are probably familiar to most mathematicians. There is, however, a special application of these laws, not so generally known, which will render valuable assistance to the civil engineer or architect when it is desired to estimate correctly the comparative economic merits of different plans and designs for structures.

Suppose it is required to build a structure to satisfy a permanent want—a bridge, for example. The want or purpose will exist longer than the life of the ordinary structure, and it will be necessary to supply a series of structures, one succeeding another. It will be advantageous, then, to determine what sort of structure will be most economical in the long run.

The truest economy does not necessarily lie in the choice of that plan whose first cost is least. The element of time or duration must enter our calculations as well as the varying costs of different types and materials.

When a structure falls out of repair and becomes unfit for further use, it is important to be able to decide correctly whether it is real economy to repair it or to erect a new one. In this case the additional lease of life received by the structure, together with its cost, must be compared with the life and and cost of the proposed new structure.

Decisions like these are commonly, but unfortunately, made in a hap-hazard manner, relying solely upon the exercise of judgment.

This faculty, in its perfection, is somewhat rare, and arises from a natural aptness for comparison and discernment, trained by a profitable and abundant experience. Some men possess it in an exalted degree, but the large majority, not so happily gifted, must sometimes have recourse to artificial aid in reaching correct conclusions. It is hoped they will find such assistance in the use of the method described below.

In order to determine the comparative values of two or more structures for a specified object, similar only in the sense that they would all fill the purpose while they lasted, we will select that one whose life is longest, and assume its cost to be the real value of the structure. The others in turn will then be compared with the first; thus we will obtain the relative value of each structure on a basis of valuation fixed by the cost of that one with the longest life. The difference between this relative value and the actual cost of the structure will be the measure of economy or of extravagance inherent in that design.

In the demonstration, which is general, provision is made for the case in which the material of the structure, after its usefulness as a whole is spent, possesses still a market value for other uses, thus allowing a rebate to be effected upon the total cost of the structure.

The following notation will be adopted:

Let C denote the cost and assumed real value of the structure with longest life.

$m$ denote its life in years.

$V, V_1, V_2$, &c., denote the equivalent relative values of other structures compared with the one of longest life.

Let $n$, $n_1$, $n_2$, &c., denote their respective lives in years. $d$, $d_1$, $d_2$, &c., denote the ratios $\frac{m}{n}, \frac{m}{n_1}, \frac{m}{n_2}$, &c. $t$ denote the compound interest on $1 for the time $m$. $p$, $p_1$, $p_2$, &c., denote the values of compound interest on $1 for the times $n, n_1, n_2$, &c. R denote the probable market value of the material in the structure of longest life, after its life has terminated. $r, r_1, r_2$, &c., denote ditto of the other structures.

If the structures of longest life were built its cost at the end of its life of $m$ years would amount to

$$C(1+t)-R \qquad (1)$$

On the other hand, by making use of a succession of structures with shorter lives of $n$ years each, the cost at the end of $n$ years would be

$$V(1+p)-r$$

At the end of $2n$ years it would be

$$V(1+p)-r+[V(1+p)-r](1+p)=$$
$$V(1+p)+V(1+p)^2-[r+r(1+p)]$$

At the end of $dn=m$ years it will be

$$V(1+p)+V(1+p)^2+\cdots+V(1+p)^d-$$
$$[r+r(1+p)+r(1+p)^2+\cdots+r(1+p)^{d-1}$$

By means of the formula for summation in geometrical progression the last expression becomes

$$\frac{(1+p)-1}{p}[V(1+p)-r] \qquad (2)$$

Equating (2) with the expression (1) and substituting $(1+t)=(1+p)^d$, we have

$$\frac{(1+t)-1}{p}[V(1+p)-r]=C(1+t)-R$$

from which the value of V is readily found.

$$V=\frac{p}{(1+t)(1+p)-(1+p)}[C(1+t)-R]+\frac{r}{1+p}$$

which reduces to

$$V=\frac{p}{t(1+p)}[C(1+t)-R]+\frac{r}{1+p} \qquad (3)$$

which is the lowest form of the general equation; but if $R=o$ and $r=o$, equation (3) reduces to

$$V=\frac{p(1+t)}{t(1+p)}C \qquad (4)$$

which will reveal comparative values in the case most often met with in practice. Formula (4) may also be written

$$V=\frac{p}{1+p}\times\frac{1+t}{t}\times C \qquad (4a)$$

The two factors $\frac{p}{1+p}$ and $\frac{1+t}{t}$ of formula (4$a$) are illustrated graphically in the accompanying diagrams A and B. The ordinates of the two curves there shown are drawn to the same scale and represent the duration of structures up to 100 years, while the abscissas represent the two factors and are laid off with different scales.

It is needless to remark that Diagram B is used to obtain the value of the factor representing the life of the most enduring structure, and that Diagram A represents the factor appertaining to the life of any other structure to be compared with the former.

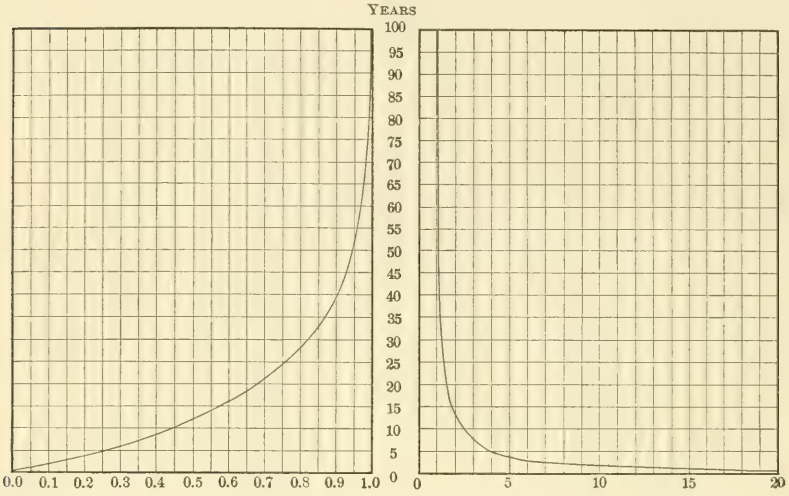
It will be seen that the abscissas of the two curves are reciprocals of each other.

DIAGRAM A.

Showing values of $\frac{p}{1+p}$ for different periods of years, with interest at 6% per annum. Ordinates represent years of duration, Abscissas represent values of $\frac{p}{1+p}$.

DIAGRAM B.

Showing values of $\frac{1+t}{t}$ for different periods of years, with interest at 6% per annum. Ordinates represent years of duration. Abscissas represent values of $\frac{1+t}{t}$.




In their computation, interest was assumed at 6% per annum.

The following examples will serve to illustrate the use of the diagrams and formulæ:

*Example* 1. It is proposed to erect a bridge of 150 feet span which is to carry a railroad track. An iron, pin-connected bridge will cost $6,900 and will last 85 years. A wooden bridge will cost $4,500 and will last 10 years; if the latter is covered at an expense of $450 it will last 20 years.

Which construction will be the most economical, if interest is rated at 6% per annum?

If the iron bridge lasting 85 years is worth C, the uncovered wooden bridge lasting 10 years is worth

$$V=\frac{p}{1+p}\times\frac{1+t}{t}\times C$$

From Diagram A we find $\frac{p}{1+p}$ for 10 years $=0.44$ and from Diagram B, $\frac{1+t}{t}$ for 85 years $=1.01$ $\therefore$

$$V=0.44\times1.01\times6900=\$3066$$

Taking next the covered wooden bridge $\frac{p}{1+p}$ for 20 years $=0.69$ $\therefore$

$$V=0.69\times1.01\times6900=\$4808.$$

A comparison of all three methods shows thus:

| | Iron Bridge | Wood Bridge uncovered. | Wood Bridge covered. |
|---|---|---|---|
| Cost..... | $6900 | $4500 | $4950 |
| Value..... | 6900 | 3066 | 4808 |
| Difference. | | $434 | $142 |

Hence the iron bridge is most economical, although costing the most. Next in order is the covered wood bridge, and the least economical of them all is the uncovered wood bridge.

*Example* 2. A wooden house has reached a state of dilapidation and is unfit for further use as it is. With repairs costing about $850, it would serve its purpose 4 years longer, while a new house, if built, would cost $6,000 and would last 40 years. Which plan is it more advisable to adopt?

$\frac{p}{1+p}$ for 4 years $=0.22$, $\frac{1+t}{t}$ for 40 years $=$ 1.11

$V = 0.22 \times 1.11 \times 6000 = \$1465$
Actual cost of repairs = 850

Difference..... $615

It is therefore very much cheaper to make the repairs.

The next example will illustrate the use of formula (3).

*Example* 3. It is required to lay a piece of railroad track. Steel rail will cost $34.00 per ton and will last 10 years; moreover, after its 10 years of service it can be sold as scrap for $22.50 per ton. Iron rail will support traffic for 5 years and will cost $27.00 per ton. Its value afterwards as scrap will be $23.50 per ton. Interest at 6%. Which is better to use?

$$V = \frac{p}{t(1+p)}[C(1+t) - R] + \frac{r}{1+p} \qquad (3)$$

With the help of interest tables we find the values of $p$ and $t$ and the formula becomes

$$V = \frac{0.338}{0.791 \times 1.338}[34 \times 1.791 - 22.50] + \frac{23.50}{1.338} = \$29.82$$

Cost of iron..... $27.00
Its relative value..... 29.82

Difference..... $2.82

It is therefore $\frac{2.82}{29.82}$ or $9\frac{1}{2}\%$ cheaper to use iron rather than steel, with the above conditions. The question of labor might have been considered in the above example by adding its expense per ton to the costs of the iron and steel.

A curious feature of formula (3) is, that from it may be obtained the theoretical value of a structure which would last forever. The formula may be written

$$V = \frac{p}{1+p} \times \frac{1+t}{t} \times C - \frac{Rp}{t(1+p)} + \frac{r}{1+p} \qquad (3a)$$

In proportion as the life of the longest lived structure is taken longer, the value of the factor $\frac{1+t}{t}$ approaches towards unity and when $m = \infty$, $\frac{1+t}{t} = 1$. With this alteration and putting $R = o$, formula (3*a*) becomes

$$V = \frac{p}{1+p} \times C + \frac{r}{1+p}$$

from which the value of C is found to be

$$C = \frac{1+p}{p} V - \frac{r}{p}$$

or

$$C = V + \frac{V - r}{p} \qquad (5)$$

When $r = o$, formula (5) should be written

$$C = \frac{1+p}{p} V \qquad (6)$$

as Diagram B can then be used to find the factor $\frac{1+p}{p}$.

*Example* 4. Suppose a structure costs $5000 and lasts 5 years, what is the relative value of a structure which would last forever? Interest at 6% per annum.

Formula (6) will be used, as $r$ is assumed $= o$. $\frac{1+p}{p}$ for 5 years is found from Diagram B to be 3.96, hence

$$C = 3.96 \times 5000 - \$19800.$$

These formulæ may be applied in a great variety of ways, but the foregoing examples illustrate their principal uses. They will often exhibit the unaided judgment at fault in its conclusions regarding the comparative values of structures when their durations are taken into account.

One fact is clearly pointed out—it is generally a great economy to make repairs if possible, rather than to rebuild, and it will be found that more money can be profitably spent in repairs than it would ordinarily be thought wise to do

In conclusion we will remark that, although the demonstration assumes, artificially, a comparison between the cost of a single structure with a long life and one of a series of structures, similar to each other, but with shorter lives; whether we decide to build the one or the other, when its life terminates, it is not necessarily advantageous to continue the series by erecting another upon the same plan. The best use of money has been effected in choosing the first design for the first structure, but after its life is spent, a certain period of time has elapsed, prices of labor and of building materials have changed, new materials come into use, types of construction have

altered and possibly the needs in the structure have become modified, therefore fresh calculations with the latest authentic data should precede and aid in the proper choice of each structure in the series, in order to attain practical economy.

## REPORTS OF ENGINEERING SOCIETIES.

ENGINEERS' CLUB OF PHILADELPHIA.—*Record of Regular Meeting, October 16th*, 1886.—Mr. J. E. Codman presented an illustrated description of a case of Low Water in a Steel Boiler, wherein the refilling of the boiler, after the exposed portions had reached a high temperature, produced no evidence of a tendency to crack in the steel.

Mr. C. O. Hering presented Tables of Equivalents of Units of Energy and Equivalents of Units of Weights and Measures, for the Reference Book.

Mr. J. H. Harden read a paper on Early Mining Operations in Berks and Chester Counties, Pennsylvania, giving the names of the charcoal furnaces, dates of construction, owners of the mines using the iron ore, location of the mines, management, cost and quantity of ore mined annually by the "Berks and Chester Mining Co.," beginning with 1836, under the management of Mr. Wm. McIlvain, continued by Mr. Hartley Potts, Mr. Robert S. Potts, Peter Ubil, Fred. Richards, and John Kenny.

He refers to the operations of the "Pennsylvania Copper Company," Captain Thomas, Manager, who died in 1808, and was succeeded by Mr Richard Trewick as Manager and Treasurer; its failure and sale by the sheriff in 1811.

Mr. Harden identifies Mr. William McIlvain as the inventor and first user of the log washer for separating the fine ore from the dirt, and referred to its patent by Mr. John Milholland.

Mr. William E. Lockwood, introduced by the Secretary, gave a brief description and review of the progress made in the efforts to determine the "hammer blow" of a locomotive's drivers, since January, 1883, when Mr. Lockwood spoke on the subject of the Shaw locomotive before the club. Stereoptical views were shown of the Ashtabula bridge before and after the accident, the conditions stated, and the suggestion made that the "hammer blow" might have been the cause.

Next were shown views of the Dudley Dynograph car, including the machinery by which the conditions of the track are determinated, and a sample sheet showing the results.

The views following were taken from mechanical drawings of a dynamometer, by Mr. Thomas Shaw, M. E., which were submitted to a sub-committee of the Committee of the Sciences and Arts of the Franklin Institute, in Oct., 1882.

Three views followed of a New Application of the Dynamometer for determining the "hammer blow" of a locomotive's drivers, as approved by a joint committee of the Franklin Institute's Committee of the Sciences and Arts; also by the Committee of the American Railway Master Mechanics Association. The report of each body was filed with the Secretary; the "Appendix" to the same, being a description of the dynamometer, was read and explained.

Following these, were shown the coupling pins and pulling bar, which attaches the tender to the locomotive, and these demonstrated in their "wear and tear" the difference between the present system of "rotating counterbalance" and "steam self-balancing counterbalance."

Three views were then shown of appliances recently constructed to prove, as Mr. Lockwood states it, that the top of the driving wheel, when in contact with the rail, moves twice as fast as the bottom, and that the bottom stands perfectly still.

## ENGINEERING NOTES.

SOME engineers still speak of electric lighting as untrustworthy. One railway engineer recently refused to light an underground railway by this light, chiefly because of its uncertainty, but another railway engineer is not only lighting Paddington station, one of the largest in London, but he is lighting all the signals by the same means, the strongest possible proof of the reliance some men put in electric lighting, and this even with an alternating current. An underground line is just the place where gas should not be used, but the engineer of the Mersey line laid great stress on the higher cost of the electric light. When railway signals are properly lighted by electricity they may be also worked by the same means.

THE report of the Suez Canal Company, read by M. de Lesseps recently, shows the receipts of 1885 to have been 65,049,945 f., and the expenses 31,021,178 f., leaving a profit of 34,028,767 f., which allows a dividend of 60 f. 40c. The return of traffic—3624 ships, of 6,335,753 tons—exceeded by 340 ships and 464,253 tons that of the previous year. The passengers numbered 205,951, against 151,916 in 1884, and 43,813 of them were English. The average time of transit was forty three hours, and though the twelve days' interruption caused by a dredger being run down led to an assemblage of 123 ships, all these got through in three days. Liberty of traveling by night with the electric light had been taken advantage of by several of the Peninsular and Oriental Company's steamers, one of which thus made the transit in seventeen hours fifty minutes. Traffic has not suffered from the economic depression, because the reduced dues have allowed the creation of fresh enterprises, or the extension of existing ones.

A 100-TON crane has just been completed by Messrs. Higginbottom and Mannock, of the Crown Ironworks, West Gorton, Manchester, for Messrs. Sir W. G. Armstrong, Mitchell & Co., Newcastle-on-Tyne. The crane is of the Goliath type, having a lift of 50 ft., and is intended for dealing with the heaviest class of castings. The crab has two barrels, both hoisting at once, and by an ingenious arrangement the weight of crab and load is equally dis-

tributed over eight wheels. The crane is rope driven, and the reversing is effected by means of friction clutches, which drive steel worms working into gun-metal worm wheels. All wheels and axles are of steel. The weight of the crab and chain is about 25 tons; the length of the chain is about 220 ft. The snatch block is of Lowmoor iron, and is so arranged that the heaviest loads can easily be turned by the hand when suspended. Altogether the crane is of massive proportions, and of good design in general and in detail, and highly creditable to Messrs. Higginbottom and Mannock.

Blasting Agents.—At the meeting of the King's College Engineering Society held recently, a paper on dynamite was read by Mr. Gask, in which an account was given of its composition and relative cost as regards gunpowder. The method of charging and tamping the holes and fixing the detonator was fully explained, and also the advantages of dynamite over gunpowder in wet ground. Great care, the author stated, has to be taken with dynamite when frozen, numerous accidents having happened from explosions when in that condition. In the discussion which followed, Mr. Heathcote explained some forms of safety cartridges, including (1) the lime cartridge; (2) cases where strontia is brought into contact with ammonia; (3) cases of breaking a vessel containing nitric acid and so bringing it in contact with picric acid. Mr. Preece drew attention to the advantages of firing charges by electricity, and the way it was done, giving as an instance the blowing up of Hell Gate, New York harbor, and explaining the arrangement of the batteries. The American substance rackarock was mentioned by Mr. Moore as being 56 times more effective than gunpowder, but inferior to dynamite. The question of the products of combustion of gunpowder, with respect to the recent quarry accident in Scotland, was also referred to.

Russian Port Improvements in the Black Sea.—Russia is making rapid progress with the port improvements she has taken in hand in the Black Sea, and upon which she proposes to spend a million sterling. At Novorossisk, which is to be the outlet for the railways of the Cis-Caucasian region, the engineers have been at work for some time past, and nearly 1,000 navvies are being assembled for vigorous operations during the winter. The first work to be taken in hand is the construction of a mole of concrete 900 yards long, which will terminate with a turret and lighthouse. The blocks of concrete to be used are to have an average weight of 27 tons, and many are already being placed in position. Along the mole a branch will be extended from the Rostoff-Vladikavkaz Railway. This will be employed principally for grain, of which the export from Novorossisk is expected to reach 100,000 tons a year. With regard to petroleum, which will rank next to corn as an article of export, a special haven will be erected on the opposite side of the new port. The bay of Novorossisk is so large that its land-locked waters afford means of establishing a dozen different ports, and thus there will be no difficulty in keeping one part of it devoted exclusively to petroleum. The site selected for the new port being situated on the side of the bay opposite to the town, the latter is to be dismantled and shifted thither. At Batoum, the works for enlarging the port are being pushed on under the guidance of M Bunge, a nephew of the Minister of Finance, who is one of the contractors for the undertaking. The cost of the improvement will be £380,000, and most of the work is to be completed within a twelvemonth.

The Forth Bridge Railway.—The following is the fourteenth quarterly report of inspection to the Board of Trade by Major-General Hutchinson, R.E., and Major Marindin, R.E., of the works in progress for the construction of the bridge over the River Forth.

During the last quarter very considerable progress has been made in all the branches of the works, as will be evident from the following remarks.

Temporary Works.—Large additions have been made to the plant, chiefly for erection purposes; these include hydraulic apparatus, goliaths, cranes, hoists, steam winches with boiler, and a number of powerful and special designed machines for riveting the 8 feet and 12 feet tubes. These machines consist of internal and external frames constructed to slide up the tubes and form supports for the rams which execute the work. The external frames, surrounded by wire netting, form cages within which the men engaged are enabled to carry on their operations with safety both to themselves and to those at work beneath them.

Permanent Works—South Queensferry.—*Main Piers.*—The lower bed-plates are now complete. On the two southern piers the skewbacks, with the junctions therewith, about 30 feet of the vertical columns and struts, and 20 feet of the bottom members of the cantilever are in position and partially riveted. On the north-east pier nearly the whole of the skewback and junction, about 15 feet of the vertical column and 10 feet of the diagonal struts, are bolted up, and the riveting is in a forward state. On the north-west pier about half of the skewback is in position, and the riveting has been commenced. The bracing girders between the skewbacks are practically complete; the horizontal tube between the eastern skewbacks is complete, and that on the western side is being riveted. Including the tubes and girders, about 1,175 tons have now been riveted.

*Cantilever and Viaduct Piers.*—The main girders on No. 3 span have been completed, and have been joined to those on Nos. 2 and 4 span; the girders on the whole of the spans have been raised to the level of 63.75 feet above O.D., the masonry having been raised 24 feet both on the cantilever piers and on piers Nos. 3 to 9 inclusive.

Inch Garvie.—*Main Piers.*—About three-quarters of the skewback on the north-west pier is bolted up, and about one-half of the riveting is complete. The upper bed-plate on the south-west pier is riveted; that on the south-east pier is erected, and the riveting is being proceeded with. Since the last report

about 56 feet have been added to the western tube, and about 32 feet to the eastern tube; about two-thirds of the northern bracing girder has been bolted up, and the greater portion riveted. About 1,000 tons of steel work have now in all been riveted.

NORTH QUEENSFERRY.—*Main Piers.*—Since the last report riveting has been commenced and is being proceeded with on all the skewbacks. The riveting of the horizontal tubes and bracing girders has been completed. The wind bracing between the vertical columns has been commenced, and both on the north and south columns it has been bolted up as far as the first intersection, a distance of about 85 feet. The erection of the upper portion of the main bracing columns is now in progress. This work is carried on with the aid of movable platforms, one on each side; these platforms (provided with fencing) are supported on girders, which again are carried by cross girders; the whole structure is raised as required by means of hydraulic rams of great power attached to the vertical columns, one to each. These platforms have now been raised about 23 feet without any difficulty.

The steel plates are raised as required in guides by steam hoists to the level of the platforms, where they are received and placed in their ultimate position by goliaths fitted with hydraulic lifting and traversing gear running on rails the whole length of the platforms. The machines for riveting the vertical columns and struts between them are put together, and two of those for the 8-feet tubes are working satisfactorily.

The total quantity of steel work riveted at North Queensferry amounts to 1,250 tons.

*Cantilever and Viaduct Piers.*—Since the last report the cantilever pier has been raised 14.5 feet and the viaduct piers 22.75 feet, or to 107 feet and 103 feet respectively above O.D. The girders have been lifted 22.5 feet, and now stand 108 feet above O.D.

GENERAL.—*Masonry and Concrete.*—Up to the present date 372,000 cubic feet of granite have been delivered, and 337,000 cubic feet set. About 98,000 cubic yards of rubble masonry and concrete work have been built, and about 20,000 tons of cement have been used.

*Steel Work.*—The whole of the skewbacks have been completed in the yard, with the exception of a small quantity of drilling and fitting for that for Inch Garvie, N.E; the fitting of the plates and angles at the important junctions of the 8 feet tubes at their crossing between the vertical columns at the North Queensferry piers is being proceeded with.

Including the horizontal and vertical tubes erected on the main piers 4,000 lineal feet of 12-feet tubes and 4,500 lineal feet of 8-feet tubes have been fitted and drilled.

Of the lattice tension members and bracing girders 7,725 feet have been drilled, and the greater portion of the latter have been erected. The main girders of the internal viaduct between the vertical columns at the North Queensferry piers have been drilled and fitted, and the top and bottom booms for the same at the South Queensferry piers have also been drilled.

In all 27,232 tons of steel have been delivered.

The average number of men employed on the works has been increased, and is now 2,545.

We are of the opinion that the works have made rapid progress during the past three months, and we have every reason for continuing to be satisfied with the way in which they are being executed.—*Engineering.*

## IRON AND STEEL NOTES.

RUSSIAN RULES FOR THE USE OF STEEL IN CONSTRUCTION.—In July, 1885, the Russian Ministry of Roads published a series of provisional regulations concerning the use of steel, of which the following is a summary:

1. Steel, whether Bessemer or Siemens-Martin, may be used in all structures.

2. In view of the great sensitiveness of steel to mechanical working it is to be noted that—

(*a.*) Plates an other sections must be tempered, after rolling, by means of the sand-bath. Care must be taken that on leaving the rolls the metal is not below a cherry-red heat.

(*b.*) Holes must not be punched, but drilled.

(*c.*) When worked cold the material must not be sheared, but cut with a chisel The edges must be planed. All bending must be done hot, and provision be made for subsequent slow cooling.

3. The material must possess the following properties:

(*a.*) It must contain 0.05 to 0.20 per cent. of carbon.

(*b*) Except for rivets, the tensile strength of all kinds of steel must be from 25.4 to 29 8 tons per square inch, extension at least 18 per cent., and the contraction of area at least 36 per cent.

For rivets the tensile strength must be from 22.2 to 25.4 tons per square inch, extension at least 20 per cent., and contraction of area at least 50 per cent. The percentage of carbon for rivets must approach the lower limit (see *a*). Extension and contraction of area are to be measured on test-pieces of 10 inches length. The test-pieces must be worked cold.

4. A strip of the metal 10 or 12 inches in length, heated to cherry-red, and then plunged into water at 85½° Fahrenheit, must not show any cracks when so bent that the inner faces of the bent piece, at a distance from the angle of one and a half times the thickness of the plate, are three times the thickness of the plate apart.

5. The permissible strain upon the material is as follows:

| | Tons per Square Inch. Steel. | Iron. |
|---|---|---|
| (*a.*) For bridges of less than 49 feet span, and also for roadway bearers (longitudinal and cross): | | |
| For tension and compression..... | 4.4 | 3.8 |
| For shearing of rivets, fastening the longitudinal to the cross-bearers, and these to the main girders..... | 3.8 | 3.2 |

| | Tons per Square Inch. Steel. | Iron. |
|---|---|---|
| For shearing of rivets in the rest of the structure..... | 4.4 | 3.8 |
| For shearing of the web of a plate girder..... | 2 9 | 2.2 |
| (*b.*) For main girders of bridges of from 49 to 95 feet span : | | |
| For tension (net cross section, after deducting rivet holes). | 4.8 | 4.4 |
| For compression (after deducting half area of rivet holes). | 4.8 | 4.4 |
| For shearing of rivets ... | 4.4 | 3.8 |
| (*c.*) For main girders of bridges of more than 95 feet span : | | |
| For tension (net cross section, after deducting rivet holes). | 5.1 | 4.6 |
| For compression (after deducting half area of rivet holes). | 5 1 | 4.6 |
| For shearing of rivets..... | 4.4. | 3.8 |
| (*d.*) For wind-bracing of bridges of more than 95 feet span : | | |
| For tension (net cross seetion) | 6.3 | 5.7 |
| For compression (after deducting half area of rivet holes). | 5.7 | 5 7 |
| For shearing of rivets.... .. | 5.1 | 4.8 |

Iron and steel may be used in the same structure, but with the limitation that in each member of a group of similar parts the same material is to be used. For instance, the top and bottom booms of a girder form such a group; the diagonals and verticals of a girder, the cross and longitudinal roadway bearers, are other such groups.

The use of steel rivets is not compulsory with steel plates.—*Foreign Abstracts of the Inst. of Civil Engineers.*

## RAILWAY NOTES.

The Railway Mileage of the British and Russian Empires.—From an official report just issued it would appear that the total length of railways opened for traffic in Russia on the 1st of June was 25,634 versts, or 17,000 miles. Of this total 3.213 versts were owned by the Government, 21.075 by public companies; 1,129 versts were in Finland, and 217 versts (the Transcaspian line) were controlled by the Minister of War. Last year about 700 miles were opened for traffic. Two railways were closed, the Sestroretsk and Oboyansk, having a united distance of 24 miles. In this manner the increase of the Russian railway system is less than in any of the great English colonies—Australia, Canada, and the Cape. In Great Britain itself, containing 2,000 miles of railway more than the whole Russian Empire, the communication system is almost complete, and the additions made every year are necessarily of a limited character; but India, with her 14,000 miles of line open, and a yearly addition of 1,000 or 2.000 miles, presses upon Russia closely, while at the rate Canada is progressing, that colony, with only 5,000,000 people, will in a few years surpass in railway mileage Russia with her 100,000,000 souls, subject to the will of the Czar. According to a recent computation there are 30,000 miles of railway in the 15 principal English colonies, including India, Canada, and Australia. Adding thereto the mileage of Great Britain, we find that the British Empire possesses three times the mileage of the Russian Empire. In Asia alone the mileage of India and Australia combined exceeds the mileage of Russia. This year Russia is making extraordinary efforts to make amends for the apathetic policy of the last five years, but with all her exertions she will not have constructed by the end of 1886 more railways than either Canada, the Cape, or Australia.

A new central railway station, said to be the largest in the world, is nearing completion at Frankfort-on the-Main. It has taken six years to construct, and will cost about £150,000, of which the Government has contributed about £100,000, and the Ludwig Railway Company the balance.

The most frequent cause of railway accidents is the failure of axles. Besides the 773 accidents on our railways reported last year as causing personal injury, there were 1,252 cases reported involving no personal injury. Of the 500 persons killed and 914 injured, ninety-six of the killed and 693 of the injured were passengers. Of these injuries the chief causes were as follows: Twenty-five persons were killed and forty-nine injured by falling between carriages and platforms; seventeen killed and 470 injured by falling on to platforms, ballast, etc.; thirty-five were killed and eleven injured while passing over the line at stations. Besides these, who were all actually passengers, fifty-eight persons were killed and twenty-one injured while passing over railways at level crossings, 250 persons were killed and 126 injured while trespassing, and to this number must be added fifty-five persons who committed suicide on railways.

Jarman's Electric Tramcar.—An attempt to produce a self-contained electrically driven tramcar has been made by Mr. Jarman, of 443 Brixton Road, London. His ideas are exemplified in a model which runs on a short length of line up steep inclines and round sharp curves. The motor is fitted between the axles of the car, and does not interfere with the present method of construction. The difficult question of heating is said to be solved by Mr. Jarman's invention, which consists of two armatures fitted to one axle. One of these drives the car in one direction, and the other propels the car in the opposite direction, so that each armature has time to cool down, should it become heated. The battery of E. P S. cells is to be placed under the seats, and the exhausted cells will be removed and replaced by charged cells as required. The motor is reversed by a simple lever. It is stated that the weight of the mechanism, including sixty storage cells, will be only 2½ tons for a forty-six passenger car. The car will be lighted by a portion of the electricity that drives the car.

## ORDNANCE AND NAVAL.

Krupp Guns.—Colonel Hennebert, in a communication to the *Correspondant*, speaks of the German artillery, says of Krupp:

"When we took some guns from the Chinese during the Tonquin Expedition they were made by Krupp; and more recently the heroic Gordon, shut up in Khartoum, mentioned the part played by these guns in the regions bathed by the waters of the White and the Blue Nile. And yet this *materiel* is far from being irreproachable. During the war of Bohemia several field pieces burst. After the war, in order to allay public agitation, trials *à outrance* were made, and these cost several young officers their lives. In 1868, General de Bœuf declared that several guns firing ordinary charges had burst; nor can it be said that the Prussian steel guns of to-day are safe In fact, between 1867 and 1870 numerous accidents occurred in Russia, England, Germany and Italy on land and on board ship." Colonel Hennebert says that during the Franco-German war 200 Krupp guns burst, as mentioned by Major Haig in a report read before the Royal Artillery Institution, and by the Duke of Cambridge, in a speech in the House of Lords on April 30th, 1876. "Out of seventy heavy guns employed against the southwest of Paris, thirty-six were disabled during the first fortnight of the bombardment by the effect of their own fire. At Versailles it was thought that if the French had held out a week longer, the German siege batteries would have been reduced to silence. It is equally certain that during the campaign on the Loire, Prince Frederick Charles had twenty-four of his guns disabled by their own fire." The Krupp system "requires delicate handling and the employment of a skillful *personnel* capable of sustained attention, and under the obligation of taking extremely minute precautions. The initial velocity and other merits of the gun are not denied.

From the French naval estimates it appears that the following arrangements have been made for building new vessels for the navy. A sum of £510,080 has been set aside for six ironclads of the first-class, of which one, the Amiral Baudin, is to be completed next year, and two, the Formidable and the Marceau, in 1888. The Neptune, which is being built at Brest, the Magenta at Toulon, and the Hoche, which has been launched at L'Orient, will not be ready to take the sea before 1889. A sum of £79,000 is to be spent upon four ironclad gunboats, two of which, the Cocyte, at Cherbourg, and the Granada, at L'Orient, are to be ready in 1887. Two large cruisers of 5,766 and 7,000 tons have been ordered to be laid down in the dockyards of La Seyne and St. Nazaire, and are to be ready in 1888. These vessels, which are to be of the protected kind, with an ironclad deck, are to have a speed of 19 knots an hour, and a sum of £160,000 is allowed for them in this year's estimates. Three first-class cruisers, the Dupuy-de-Lôme, the Jean Bar, and the Alger, each of 4,200 tons, and each to cost £184,000, have just been laid down at Cherbourg, Brest, and Rochefort. Two second-class cruisers and three of the third class are also included in the list of ships to be built in 1887, and a sum of £144,000 is allowed for these vessels, which are to be very fast, in next year's expenditure. Three torpedo cruisers, the Epervier, the Vauteur, and the Faucon, 51 torpedo boats ordered from private firms, and one seagoing torpedo vessel, the Ouragan, which is to have a speed of 25 knots an hour, are also to be ready next year, a sum of £128,000 being allowed for their completion. A credit of £109,720 is allowed for two dispatch boats, which are to be completed, three transports, and two sailing frigates, so that altogether there are in course of construction or armament six ironclads, four ironclad gunboats, ten cruisers, three crusing torpedo boats, three dispatch boats, three transports, 52 torpedo boats, two sailing frigates, and one third-class torpedo boat, the total credit being allowed for them in the course of next year being £1 190,024.

It is stated that the late Imperial yacht Livadia, upon the magnificent equipment and gorgeous embellishment of which Alexander II. lavished so many millions of roubles, appears at last destined to be put to some practical use. The Livadia arrived at Sebastopol about Sept. 1st from Nicolaieff. She has already been denuded of her former sumptuous appointments and decorations, but is now to undergo a further and radical cleaning out, and will then be made available as a troopship. Her chief mission will be the transport of troops from Sebastopol to Batoum. If her preliminary trips happen to be made in some of the heavy and choppy seas which are not unfrequently experienced in these waters, the Livadia's doubtful sea-going capacity will be somewhat severely tested, and her behavior will be watched with some interest by those naval experts and designers who approved or condemned her structural lines before she left the slips of Elder and Pearce. At all events, with moderately fair weather the Livadia will, after being cleared out and refitted, be capable of carrying in a single short voyage an enormous number of troops in case of need. We need hardly tell our readers that the statement only confirms another, made when the ship was launched, namely, that she was called a yacht, instead of troopship, to throw dust in the eyes of Europe.

A Russian Torpedo Boat.—The Wiborg torpedo boat, built for the Russian Government by Messrs. Thomson, of Clydebank, completed a most exhaustive series of experimental trials recently. The vessel is so lightly and delicately constructed that the Russian Admiralty specified a very much larger number of experimental trials than is usual in this class of vessel. A series of trials has been carried out, about twelve in number, to determine the best form of propeller for the vessel. In addition to these trials, a series of experiments has been made out to determine the maneuvering capabilities of the vessel, another series testing her sea-going qualities, and a third series to determine the rate of consumption of fuel. In all, the vessel has had nearly twenty trial trips. The Wiborg is 148 feet long, 17 feet broad, and 9½ feet deep. She carries two revolver Hotchkiss guns, and four torpedo tubes or guns. She can carry coal to steam 4,500 knots at 10 knots per hour. Her machinery is duplicated, and in fact she is the first torpedo boat built in this country with twin screws.

Messrs. Thomson made this departure in face of the fact that the leading torpedo boat builders had predicted that the adoption of twin screws meant a considerable loss of efficiency. The vessel is divided into twenty-two water-tight subdivisions. The engines and boilers are encircled by a belt of coal protection The torpedo tubes forward are protected from machine gun fire. The vessel is fitted with a bow and stern rudder. At a former trial, the Wiborg attained a speed of 22 knots per hour. Since then she has been timed in a very much more deeply laden condition, such as would represent her in complete fighting trim, with coals on board for a long sea cruise, and she has maintained on three different days a speed of nearly 21 knots for four hours at each time together. Recently, during one of these four-hour runs, she ran between the Cloch and Cumbrae Lights in 39 minutes. This gives a mean speed of 21 knots per hour—the least time in which this well-known run has been made. The vessel turns a half-circle in a little over half a minute.

The Paradox Gun.—A trial of a new gun for sportsmen, which combines the advantages of a rifle and a shot gun, and discharges shot with the pattern and penetration of a 12-bore and conical bullets up to 100 yards with the accuracy of an express rifle, was held on October 6 at the Kensal Green range of Messrs. Holland, the gun-makers of New Bond street. The gun has been brought under the notice of the government as being a useful weapon for the service, by reason of the capacity for shooting slugs and bullets. Many attempts have been made to bring out a thoroughly satisfactory weapon of the kind, and as the difficulty has at last been surmounted, the gun has been called the "Paradox." It is an ordinary 12-bore shot gun, but it is rifled on the ratchet principle for the space of an inch from the muzzle or thereabouts, and then the rifling gradually tapers away to the cylinder. The trial commenced by the operator shooting ten consecutive right and left shots at 50 yards range, with three drachms of powder and pellets weighing $1\frac{1}{4}$ oz., and the whole of these were placed within a space measuring $2\frac{1}{2}$ inches by $2\frac{1}{8}$ inches. Ten consecutive right and left shots were then fired at 100 yards, and were put into a space $3\frac{3}{4}$ inches by $5\frac{3}{8}$ inches. The right barrel of the Paradox gun was then shot with three drachms of powder and $1\frac{1}{8}$ oz. of No. 6 shot at 40 yards, and 206 pellets were lodged in the 30-inch circle, while 137 were put into a similar circle by the right barrel of an ordinary cylinder gun. The left barrel of the Paradox was then tried, and 194 pellets were put into the circle, as against 51 of the left barrel of the cylinder. A right and left from the Paradox at the same distance, and with similar charges, put 179 and 203 pellets into the two circles respectively. The Paradox was then shot at 40 yards with three drachms of powder and $1\frac{3}{8}$ oz. of A A A shot, numbering about 50 pellets. The right barrel put 39 into the circle and the left 36, and the cylinder only put in 27 from the right barrel and 15 from the left. The wind having dropped a little, another trial of 10 shots at 100 yards was made, and this time the 10 shots were put into a space measuring $3\frac{1}{2}$ inches by 4 inches, and nine of these were within $2\frac{1}{4}$ inches by $3\frac{1}{2}$ inches—a marvelous performance. To give an idea of the comparative shooting of the cylinder and the Paradox at 100 yards with a bullet, it may be stated that the former could only put the bullets within a space of 3 feet square, while the latter could almost do it within 3 inches square.

Net Defenses against Torpedoes. — Important experiments with the net defense booms manufactured by Messrs. Bullivant took place at Portsmouth on board the Dido, on Oct. 8, under Admiralty directions, and in the presence of naval and dockyard officers. The extreme difficulty of using the wooden booms in action having long been felt, a few years ago the matter engaged the attention of the authorities at Malta Dockyard, who fitted to the Superb the ordinary booms, but added such appliances that the time occupied in lowering the net was reduced to one-fifth. Still, the wooden booms were adhered to, and the result is that, with the exception of the Superb, there is no vessel in the service that can run out her nets in less than two hours. By Mr. Bullivant's system the work can be done in ten minutes or a quarter of an hour. Several naval officers have often declared that, were they in action, they would totally disregard their net defenses, owing to their unwieldy working, and trust to their guns and helm. It was generally agreed by both the naval and dockyard professional officers who were present at the time that, although the invention may be crude in some of its details, the principle is a thoroughly sound one. The cumbersome wooden spar weighs 11 cwt., whilst Mr. Bullivant's spar, which is of the same length, and consists of a steel tube, weighs 5 cwt. Whether it is strong enough will have to be proved by tests at sea. Next, the wooden beams are made fast to the ship's side by means of a hook which may at any time become unshipped. The new invention is attached by a universal joint, by means of which the boom may be held in any conceivable position, but the most important feature of the boom is the traveler. Under the system at present in vogue the nets are attached to the booms by men in boats told off for the purpose, and it can readily be conceived how impossible this task would be in action, while with the nets already in position great difficulty is experienced in making the ship readily answer her helm. In the Superb the nets are made fast on board to the head of the booms, and then thrown out to sea, thereby placing a great strain on the spars. The Bullivant system is simpler than either. The facility with which the traveler works was exemplified during the trial in nearly a dozen ways, the nets being entirely submerged while the booms were run fore and aft, and also covered by water. In a second or two they were square with the ship and set taut, then the net was hauled in close to the ship, and the booms once more assumed a perpendicular position. In this way the net was brailed up, and in a very few minutes the booms and net were again ready for action. The importance of the invention is likely to be felt in another direction of no less weight. The Russians are

reported to have discovered a torpedo which cuts the nets and explodes at the ship. It is so arranged as to burst only at the second object it touches. Now, with the wooden booms, the placing of the two nets is such a tedious process as to be for all useful purposes impracticable. With the Bullivant boom it can easily be done, and would, therefore, be a protection against the new torpedo. Such are the merits of the invention; but in the opinion of men best able to judge it is by no means perfect. It was thought, in the first place, to be too frail both in the boom and in the joint, also that the brails and leads would require a further exercise of the ingenuity of the inventor. There are other minor details which demand improvement, but as to the general principle there was an unanimous opinion that it was the right one. It was also pointed out that in estimating the weight and bulk of spare spars in a ship the new invention was one to be commended, for not only is it lighter, but it can be made in two parts, and joined in the middle by means of a screw. It is also cheaper than the wooden spars, and being so much lighter the distance of 45 feet now observed between the booms on the side of a man-of war can be reduced to 30 feet, thereby imposing less strain and securing the tautness of the net. The experiments being considered a success, the booms will now be tried at sea on one of the ships about to be commissioned.

THE SPANISH NAVY.—The Spanish navy has been placed under the control, as Minister of Marine, of Admiral de Beranger, who is credited with great reforming intentions. Admiral de Beranger is of French origin, and is allied by birth with the Montmorencys, the La Rochefoucaulds, and other great French families. His grandfather quitted France on the outbreak of the great revolution, and he himself entered the Spanish naval service, in which he has attained reputation. The projects which Admiral de Beranger has now in hand are threefold: first, the creation of a new fleet at a cost of £7,596,000; second, the completion and improvement of the existing fleet at a cost of £904,000; and third, the purchase of additional *materiel* for the arsenals of Spain at a cost of £500,000. Admiral de Beranger proposes to carry out these reorganizations of the Spanish navy in four years, but he proposes to spread the expense over nine years, so as to involve a charge to the state for that period of about £1,000,000 per annum. Further, Admiral de Beranger does not propose to charge this £1,000,000 per annum against the ordinary revenue of Spain, but he hopes to obtain it through the sale of national forests. To go a little more into the projects of Admiral de Beranger, we may state that he proposes, first, the construction of eleven large cruisers, each of 3,000 to 5,000 tons, and able to steam 21 miles per hour; secondly, the construction of ten cruisers, of 1,000 to 1,500 tons each, and able to steam from 18 to 21 miles per hour; thirdly, the construction of 96 first-class torpedo boats, of 100 to 120 tons each; fourthly, the construction of 42 second-class torpedo boats of 60 to 70 tons each; and fifthly, the construction of a workshop transport of 3,000 tons. Admiral de Beranger further wishes to build for the service of distant colonies 16 gunboats of 350 to 500 tons each, and able to steam 16 to 18 miles per hour, and 16 gunboats of 200 to 250 tons each, able to steam 14 to 16 miles per hour. If these 32 vessels are built, they will all be armed with torpedoes and mitrailleuses. Finally, Admiral de Beranger wishes to build for the colonial service 20 steam shallops, of from 30 to 35 tons each. The cost of building all these vessels is estimated, as previously stated, at £7,596,000. Negotiations for their construction have been commenced with sundry foreign firms, who are prepared, it is stated, to accept the terms of execution and payment proposed by Admiral de Beranger, viz.: four years and nine years respectively. The following vessels are now actually in course of construction, and will involve a cost of £904,000, proposed to be drawn from the sale of the national forests of Spain, exclusive of the annual credits allowed in the budget for naval purposes: The Pelayo, ironclad, 9,800 tons burthen, building at the Seyne Works, France; the Regent, first-class cruiser, 4,000 tons, building in England; the Cuba and the Suzon, torpedo cruisers, 1,050 tons each, building in England; the Destructive, torpedo boat, 350 tons, building in England; four first-class torpedo boats; three cruisers already launched, the Alfonso XII., the Queen Christina, and the Queen Mercedes, 3,090 tons each; and five second-class cruisers, already afloat, but not yet finished, 1,055 tons each. When all these vessels are ready for sea, Spain will have, Admiral de Beranger considers, a first-class squadron and a reserve squadron. The first class squadron will be composed of the Pelayo, ironclad, 12 first-class cruisers, 13 second-class and third-class cruisers, 10 first-class torpedo boats, 50 second-class torpedo boats, and one transport. The second-class squadron will be composed of two old ironclads, the Victoria and the Numancia; six first-class cruisers, 3,342 tons each; 32 second and third-class vessels; and 53 small vessels, without reckoning 30 gunboats still in a stage of projection. The present staff of the Spanish navy comprises 8,000 officers and sailors, and between 5,000 and 6,000 marines; but if the projects of Admiral de Beranger are all carried out, this staff will have, of course, to be considerably increased.

## BOOK NOTICES.

### PUBLICATIONS RECEIVED.

PAPERS of the Institution of Civil Engineers: No. 2100.—Heliography; or the Actinic Copying of Engineering Drawings. By Benjamin Howarth Thwaite, M. Inst. C. E.

No. 2,161.—The Bilbao Iron Works. By Neil Kennedy, M. Inst. C. E.

No. 2,199.—Note on the Gold Fields of South Africa. By Sidney Howard Farrar.

The Roorkee Hydraulic Experiments. By E. S. Bellasis, Assoc. M. Inst. C. E.

A Text Book on Steam and Steam Engines. By Andrew Jamieson. London: Charles Griffin & Co.

This is a course of thirty lectures, presenting in a concise way the History of the Early En-

gines, Heat, Evaporation, Expansion of Steam, Valve Motions, Boilers, and Locomotives.

To adapt it to school use, questions are appended to many of the chapters.

The illustrations are numerous but are badly printed.

Precious Stones in Nature, Art and Literature. By S. M. Burnham. Boston: Bradlee Whidden.

The chief difference between this and the several other books bearing similar titles, is suggested by the reference in the title to Art and Literature.

The book is beautifully printed and is worthy of a conspicuous place in a reference library.

Regulations Governing the Uniform of Commissioned Officers, Warrant Officers and Enlisted Men of the Navy of the United States. Washington: Gov't Printing Office.

The title of this book gives sufficient account of its contents. It is only necessary to add that there are twenty-three plates illustrating the text. Most of them are in color.

ELEMENTS OF INORGANIC CHEMISTRY. Descriptive and Qualitative. By JAMES H. SHEPARD. Pp. 378 D. C. Heath & Co., Boston. 1886. Price, $1.25.

Of text books in Chemistry there are many. A few are good, but the greater number are indifferent or bad. Those who teach the science, in looking for a suitable text book to place in the hands of their students, become discouraged; after examining the existing works, and endeavoring to produce something better, their efforts frequently result in failure. The work before us does not come within this category. It has been carefully written, and then carefully read both in manuscript and proof by Prof. Ira Remsen, of the Johns Hopkins University, and is in every way admirably adapted to the wants of both teacher and student. By its means chemistry is taught practically The student is compelled to experiment for himself, and does his own thinking, and it is then left to the teacher to explain difficulties and to add to the student's knowledge from his own greater supply of information. Solely on its merits, the book has already been adopted in nearly seventy-five colleges and schools.

ELECTRICITY IN THE SERVICE OF MAN. By R. WORMELL, D. Sc. New York and London: Cassell & Co

Applications of electricity have multiplied so rapidly of late, that the last treatise on the subject is presumably the best. This work is voluminous and is abundantly illustrated with excellent wood cuts. A liberal amount of space is given to electric motors as well as to telephones.

ELECTRICITY TREATED EXPERIMENTALLY. By LINNEAUS CUMMING, M. A. London: Rivingtons.

This book presents the subject of Electricity as an experimental science, and is therefore adapted to the wants of an instructor who has the means of illustration at hand.

The principle to be illustrated is kept carefully in view, and the phenomena produced are skillfully interpreted.

The work is in four parts: Magnetism; Frictional Electricity; Voltaic Electricity; Thermo-Electricity. Questions for the instructor's use are appended to the several parts.

The illustrations are numerous and excellent.

## MISCELLANEOUS.

M. DEPREZ's experiments on electrical motive power, which have now been carried on for some time at Creil at the expense of Messrs. Rothschild, seem to be in a fair way of bearing important fruit. According to the results, it appears that M. Deprez can with only one generator and one receptor, transmit to a distance of thirty-five miles a force of fifty-two horse-power, and that the machinery is now working regularly and continuously. The maximum electro-motive force is 6,200 volts, though prior to the construction of M. Deprez's apparatus, the maximum force did not exceed 2,000. This is a high rate of tension, though, to judge by the experience of the past six months, it does not seem to be attended with danger, no accident of any kind having arisen; and it is perfectly feasible to leave the transmitting wires uncovered on poles, so long as they are sufficiently high to be out of reach of the hand. The cost of a circular line of seventy miles for a fifty horse-power of transmission is estimated at about £5,000, though this price would be much diminished if the machines were frequently constructed. It seems probable that a new and very practicable motor power will shortly be available for industrial purposes.

ELECTROLYSIS.—M. Renard has conducted a series of experiments to demonstrate that the simple laws of electrolysis, which frequently do not seem to hold, become clearly apparent if sufficiently diluted solutions are employed. His solutions were of a concentration varying from 1, 2, 3, &c., ten-thousandths up to 1024 ten-thousandths. Of these solutions he used one litre, with a thermopile yielding 3.65 volts, and employing two electrodes of 226 square millimeters surface (3½ square inches). The negative electrode consisted of a platinum disk which was constantly moved to and fro by the arm of an electric bell in order to offer fresh liquid to the surface. The positive electrode was a plate of the respective metal. M. Renard summarizes his results as follows: In sufficiently diluted solutions the weights of metal precipitated are proportional to the degrees of concentration; the weights of metal are proportional to their chemical equivalents; and since, according to Faraday's law, these weights precipitated are also proportional to the current intensities, all metal solutions containing equivalent metal weights must have the same conductivity. This latter law had, by means of direct experiments, already been established by M. Bouty.

THE NATURE OF EARTH CURRENTS.—M. Landeren, a French *savant*, has for years past been making observations on the nature and *rôle* of earth currents at the city of Tortosa, and some of his remarks thereon are worthy of note. He believes that he has discovered the existence of telluric currents produced by the

wind, and he finds that the direction of the currents change during whole months at a time. From various experiments with aerial lines, a Mascart electrometer and galvanometers, he obtains the result that when the telluric current and the wind are both in the same direction, or if the angle their directions form is under a right angle, the deflections of the observing instrument are of the same sign; but when the wind is directly opposite in direction to the current, or at an angle over a right angle, the deflections are of a different sign. He concludes that the potential of the telluric current is very feeble; and that the wind electrifies the earth rather than the wire, and develops in the earth a current of the same direction as itself, flowing through the soil over a large cross-section. While upon this subject we may mention a published report from America (for the truth of which, of course, we cannot vouch) to the effect that Mr. Edison is occupying his mind with the problem of utilizing earth currents for telegraphic purposes. How he is to do it without the use of aerial wires is one of the mysteries of the report in question.

THE Norwegian nickel and copper industries are suffering from great depression, the demand and prices, chiefly for the former metal, being reduced to a minimum. During the last few years several mines have been closed, and recently another nickel mine and a copper mine have had to follow this example. On the other hand, the owners of the Great Roraas Copper Works have decided upon adopting a new method for an improved and more profitable production of their copper, in which electricity plays the principal part, the introduction of which will cost £8,000.

AT a recent meeting of the Berlin Physical Society, Herr C. Baur described experiments he had made with water-jets, which, issuing from a conically pointed tube in parabolic curves, were acted upon by certain musical tones, so that, at some distance from the mouth of the tube, they showed a rotation, and that the jet, though broken up into drops behind the apex of the parabola, contracted into a continuous jet. The thinner was the jet the higher must be the tone towards which it was sensitive; the thicker the jet the deeper the tone. Herr Baur had instituted further experiments with water-jets which he caused to fall on plates. Under certain circumstances there thus arose quite pure tones, which continued as long as the jet hit on the plate. The experiments succeeded best with a Weissmann apparatus, when the jet issued under a pressure of 10cm. water from a lateral opening of 4mm. in diameter without tube. Thin window-glass plates and metal plates, which, resting on pedestals, had free movement of vibration, were best suited as receiving-plates. The tone was most certain of occurrence when the node lines of the plates were supported. In the jet itself appeared nodes and ventral segments at some distance from the opening. They were most distinct and regular at its middle; away in the direction of the plates they again became indistinct. If the metal plate and the water, acidified beforehand, were connected with a galvanic cell and a telephone, then no interruption of the current could be recognized during the time of the sounding. The contact of the water-jet with the plate must necessarily, therefore, be continuous. Herr Baur deemed this mode of excitation very well adapted to the purpose of studying the vibrations of plates.

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Rather more than six months prior to the death of Mr. D. Van Nostrand, the publisher and founder of this magazine, had entered into an arrangement with Mr. N. M. Forney, lately of the *Railroad Gazette*, New York, to transfer the publication of it to him Mr. Forney's health, however, at the time, prevented the completion of the agreement, and by mutual consent the matter was laid over for another year, with the understanding that Mr. Van Nostrand should continue the publication, and if Mr. Forney's health permitted, then the agreement should be consummated on or before the end of 1886. Mr Van Nostrand died June 14, and the present writer, who had the management of his business, arranged with Mr. Forney to make the transfer after the issue of the December number.

It is deemed fitting, therefore, that in the final issue of the periodical that has so long and so eminently borne his name, some reference should be made to his life and work. The portrait which accompanies this number (see frontispiece) was engraved from a photograph taken some years since and represents him as he appeared before ill-health had made any inroads on him. Practically, however, he was but a little changed from this at the time of his death, nor during the latter years of his life had age made any material difference in his personal appearance. To the casual observer his physical conditions excited no remarks, but to those nearer him there was a change plainly visible. His activity had departed, his original vigorous manner had given place to one of apparent weariness and lassitude. For nearly six months previous to his death he had abandoned his usual attention to business, albeit he maintained his interest in it and he kept on, hoping that he would still be able once more to take his usual place. The biographical sketch that is contributed to this final number of the magazine, was written by a warm personal friend, who had known him intimately for many years, and it is offered as a memorial to the readers of the magazine, who, if they had never met him or did not know him, will, at least, in this way, be afforded more intimate knowledge of its founder and its publisher.

WM. H. FARRINGTON.

## ADIEU.

To the American contributors to this magazine is due the credit of earning for it the reputation of being a representative journal of American engineering. To all such as have thus aided the editor at any time in his seventeen years of service, he desires now in his own name to tender his thanks and bid them and his readers adieu. GEO. W. PLYMPTON.